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HAZARD CLASSIFICATION TESTING OF M-10 AND M-1 PROPELLANTS USED IN 81 MM, 155 MM AND 8-INCH AMMUNITION

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

In support of the U.S. Army Plant Modernization Program and under the guidance of the Manufacturing Technology Division, Special Technology Branch of ARRADCOM, an extensive series of tests has been conducted to determine the hazard classification of selected plant operations in the new propellant loading facilities. These test evaluations have concentrated on the establishment of critical height and safe separation conditions for these operations such that they can be classified as a Class 1.3 operation as opposed to the more hazardous Class 1.1 explosive operation.

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20. ABSTRACT (Continued)

These hazard classification tests concentrated on two primary areas. The first area of interest was on the receiving lines for M-10 propellant and the eventual loading of M-10 into the 81 mm mortar increments. The second area of interest was in the receiving lines for M-1 propellant which were sequentially loaded into bags which already contained either the black powder igniter, the clean burning igniter (CBI) or the center core igniter.

The results of the test programs clearly indicated that safe separation distances for these operations could be established and that the operations could be classified as 1.3 in accordance with the AMCR 385-100 as amended. It was also determined that should a fire occur in an M-10 loading hopper, this fire could be prevented from transcending into a high order detonation by limiting the height of the propellant in the hopper to not more than 31.8 cm.

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INTRODUCTION

This report describes a series of full-scale test evaluations which was conducted in support of the U.S. Army Plant Modernization Program and the activities of the Lone Star, Kansas, Iowa and Indiana Army Ammunition Plants. The tests were performed under the guidance of the Manufacturing Technology Division of ARRADCOM, Dover, New Jersey, and are divided into two groups of tests, both answering the same questions about different processing activities. The first of these activities is the loading of M-10 propellant into 81 mm mortar increments and includes both the receipt of the M-10 propellant at the loading plant and its eventual storage in bins after loading. The second activity concerns the loading and transporting of base pad and center core igniters into the propellant bags which are eventually filled with M-1 propellant. This processing activity includes the receipt and handling of the M-1 propellant as it is received by the load assembly and pack operation.

The questions to be answered by the test series center on the determination of whether these activities can be controlled or limited such that a major detonation will not occur; and, should a fire be ignited at any point in the process activities, can this fire be controlled through either limitation of the separation distance and/or application of a water deluge system to extinguish extraneous fires. Since the Army Ammunition Plants are currently undergoing extensive modifications and in some cases totally new facilities are being constructed, it was most important that a determination be made of the hazard classification of these activities. This urgency arose when it was judged that expensive modifications would have to be made to existing facilities and or construction plans if these operations remained a Class 1.1 explosive operation as opposed to the much less hazardous Class 1.3 operation.

A series of tests which was conducted and is reported herein was aimed at evaluating specific processing operations in which a detonation or a fire could conceivably result in major property damage and even loss of human life.

The hazard classification of the activities associated with the loading of the 81 mm mortar increments examined the receipt of the M-10 propellant in the cardboard shipping drums and the loading of the M-10 propellant into hoppers. The concern here was to establish a safe separation distance on a conveyor system for the cardboard drums in which M-10 propellant is received at the LAP operation. The propellant is then dumped into hoppers which feed the material into the mortar increment loading process. Originally it was believed that the safe separation of multiple loading hoppers would be of concern. It was quickly established, however, that the plant layout would require the hoppers to be fitted with a 3-meter high stack, thus allowing for the confinement of combustion gases foregoing the probabilities of propagation between stacks. Realizing that a fire in M-10 propellant could transcend into a high order detonation, it was important that a critical loading height be established such that a

detonation would not occur. Tests were conducted to demonstrate the potential hazard, a safe separation distance was established for the cardboard shipping drums and a critical height of M-10 in the loading hoppers was determined. Additional tests verified that the 81 mm mortar increments, after loading, could be temporarily held in storage bins containing up to 500 increments each without risk of mass detonation.

In the second series of hazard classification tests, the propelling charge loading processes for the 155 mm and 8-in. howitzer gun were examined for their possible classification as a 1.3 fire hazard. As a safety measure, each of these processing activities are normally conducted in buildings separated by some physical separation distance. This distance is designed such that a detonation or fire event in one building should not be propagated to any adjacent building. Each processing activity is, however, connected by a tunnel ramp conveyor system which transports in-process materials from one activity to the next. It is through these conveyor systems and tunnel ramps that propagation is most likely to occur; hence, when considering the down classification of an activity from a detonation hazard to a less severe fire hazard, a determination must be made as to how these tunnel-ramp events can be controlled. The second series of tests was directed at the examination of the transport of propelling charge igniter assemblies through a tunnel ramp conveyor system into the assembly building. The propelling charge bags are next loaded with M-1 propellant which is received through a tunnel ramp conveyor system coming in from another direction to the assembly building. These two conveyor systems were examined and a series of full-scale tests was designed and conducted to determine if a high order detonation would occur and could that detonation be prevented. Early tests immediately demonstrated that a high order detonation could be prevented, hence it became then desirable to limit the severity of a fire event and to establish procedures for the prevention of fire propagation through the tunnel.

In the succeeding sections of this report, the experimental test procedures are detailed in Section II and complete test results are presented. Conclusions drawn from the full-scale test series are described in Section III and recommendations for safe handling procedures and hazard classification of the various activities are presented in Section IV.

EXPERIMENTAL PROCEDURES AND TEST RESULTS

M-10 Propellant Processing and Loading into 81 mm Mortar Increments

M-10 in Receiving Drums

M-10 propellant is a very rapid burning propellant containing 98 percent nitrocellulose, one percent potassium sulfate flash suppressor and one percent diphenylamine. Its burning rate is 2.5 times that of M-1 propellant, hence there was great concern among the DARCOM safety offices as to the safe separation requirements and safe handling procedures for this propellant in the new modernized ammunition loading plant. Figure 1 shows a photograph of 2.3 kg of M-10 propellant burning approximately five seconds after ignition. This quantity of propellant was contained in a cardboard shipping drum which had been placed in the center of four acceptor drums for the test firing as shown in Figure 2. It can be seen that the M-10 burned so rapidly that none of the four acceptor drums were even scorched much less burned to destruction. In Figure 3 a closeup view of the donor drum after the test firing shows it to be slightly charred but sufficient heat was not transferred to the cardboard to cause burning. (Lids on M-10 drums not taped).

The results of 21 such tests are listed in Table I and clearly indicate that propagation of a fire occurring in a donor drum will not be transmitted to an acceptor placed in immediate contact with the donor. The test series shown in Table I indicates that separation tests were conducted from 1.5 meters down to 0 meters standoff and the total burn time of the donor drum was approximately 8.0 seconds. Tests 48, 50 and 51 were conducted to determine if increased quantities of M-10 propellant would generate propagation to the acceptor cartons. The test results indicate that no propagation would occur. Most of the tests, and in particular Tests 52 through 65, were conducted with a quantity of 2.3 kg in the donor drum, this being the quantity of propellant normally received at the loading plant in each of the shipping cartons. (Drum or carton dimension .3 m dia. x .3 m high).

It can be concluded from the test program that 14 confirmatory tests (56 data points) yielded no propagation to the acceptor shipping drums, and a safe separation distance of 0 meters is demonstrated. These results indicate that it would be safe practice to allow the shipping drums on the receiving conveyor to be touching one another without risk of propagation should a fire occur in any of the drums.

M-10 in Hoppers - Safe Separation

In the processing steps at the modernized ammunition plant leading to the loading of 81 mm mortar increments with M-10 propellant, the material is received in cardboard drums as discussed in the previous paragraphs and eventually is dumped into hoppers as shown diagrammatically in Figure 4. Early in the test program following the proposed design of the modernized ammunition plant, it was believed that several of these hoppers would be

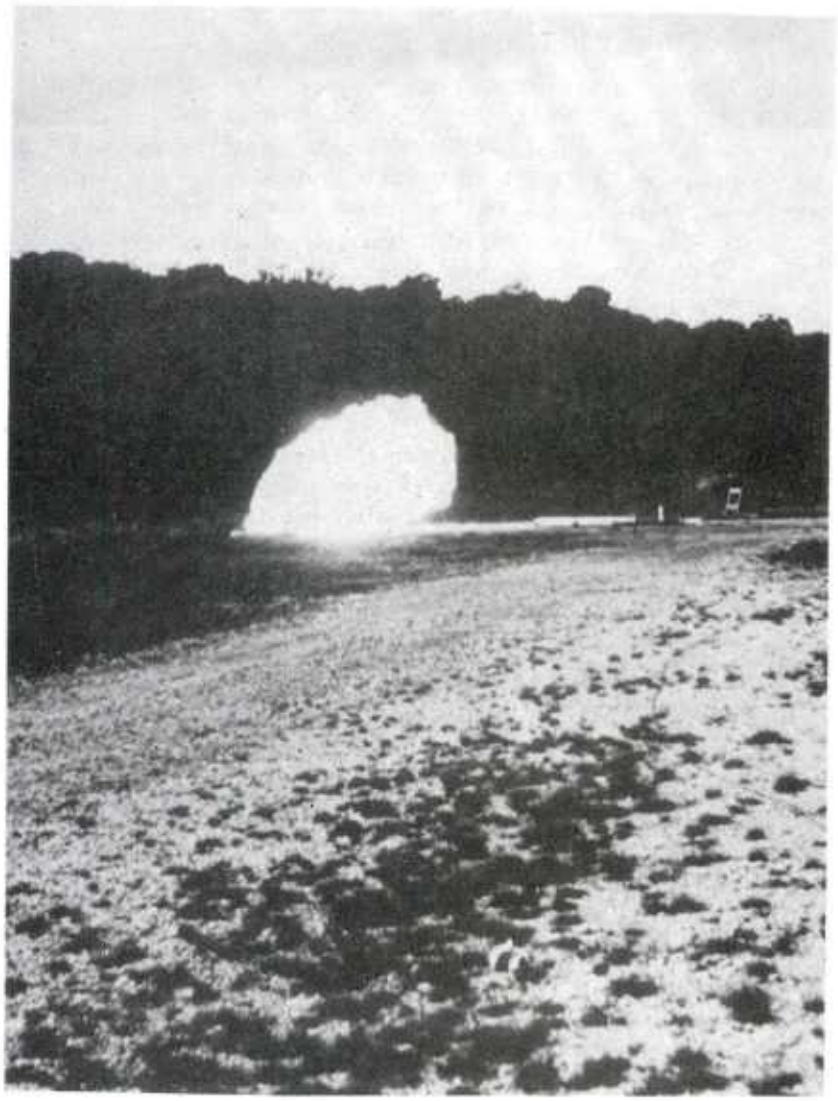


FIGURE 1. VIEW OF DONOR DRUM BURNING, WITH NO PROPAGATION TO ACCEPTORS

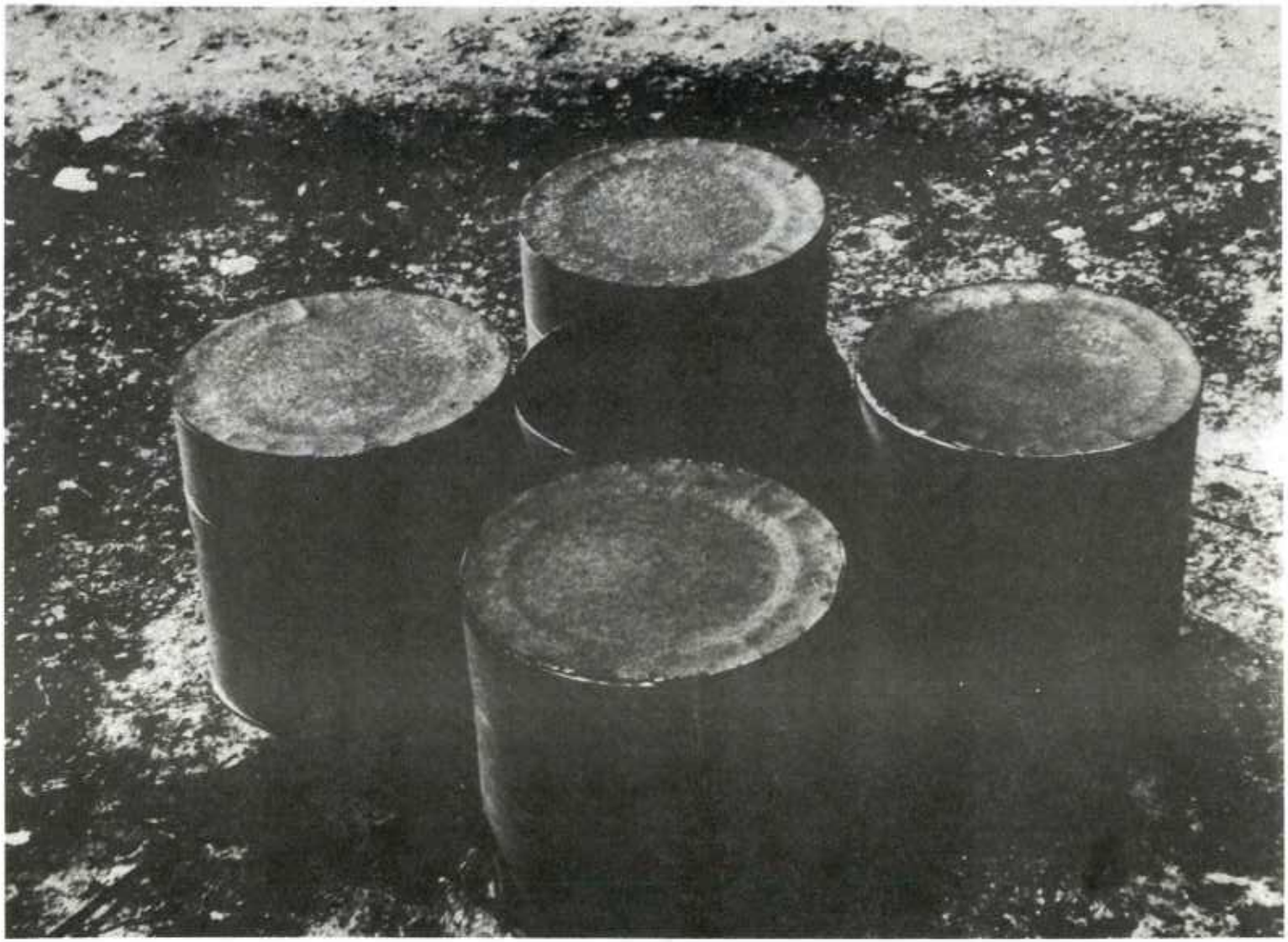


FIGURE 2. DRUMS OF M-10 PROPELLANT PLACED AT ZERO SEPARATION DISTANCE. DONOR IS IN CENTER WITH LID BLOWN OFF.

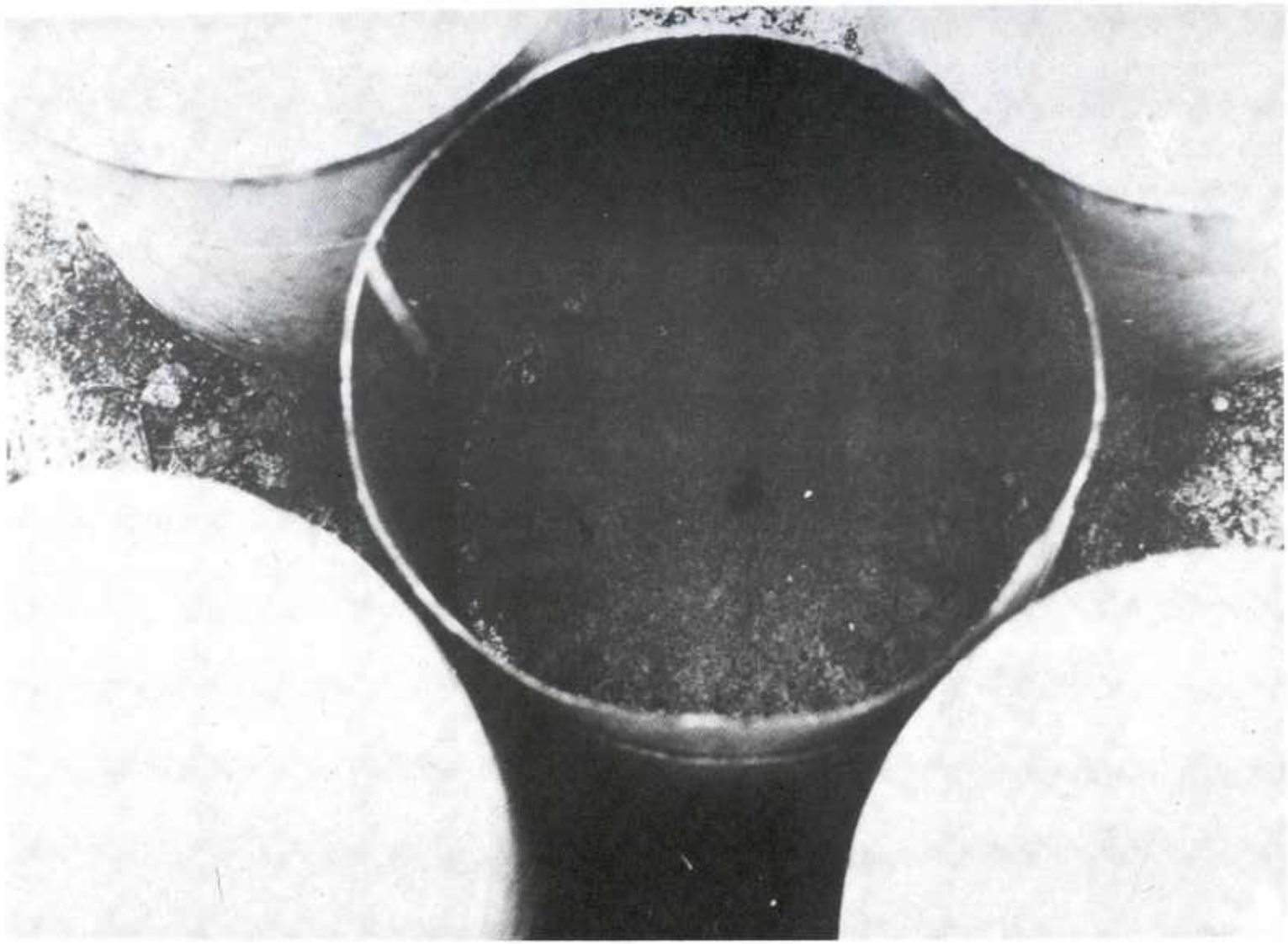


FIGURE 3. CLOSE-UP VIEW OF DONOR DRUM AFTER TEST ACCEPTOR DRUMS NOT BURNED

Table I.

SAFE SEPARATION - M-10 PROPELLANT IN 0.3 m O.D. X 0.3 m HIGH CARDBOARD SHIPPING CONTAINERS

Test No.	Separation Distance Edge-to-Edge (meters)	Propellant Weight (Kgs)	Propagation Acc #1	Acc #2	Acc #3	Acc #4	Burn Time (secs)
45	1.5	2.3	No	No	No	No	7.5
46	0.6	2.3	No	No	No	No	7.5
47	0.2	2.3	No	No	No	No	7
48	1.5	13 in donor 2.3 in ea Acc.	No	No	No	No	8.5
49	0	2.3	No	No	No	No	7
50	0	13 in donor 2.3 in ea Acc.	No	No	No	No	8.5
51	0	13 in donor & Acc. #2 Acc # 1, 3 & 4 have 23	No	No	No	No	8
52 thru 65 (14 tests)	0	2.3	No	No	No	No	7 to 7.5

Notes: Donor cartons ignited at bottom with Atlas 300 Electric Match.

Tests 48, 50 and 51 conducted to determine if increased quantities of M-10 propellant would generate propagation to acceptor cartons.

In all tests the inside of the donor carton was blackened and charred while the edge of the acceptor lids showed signs of being singed or scorched.

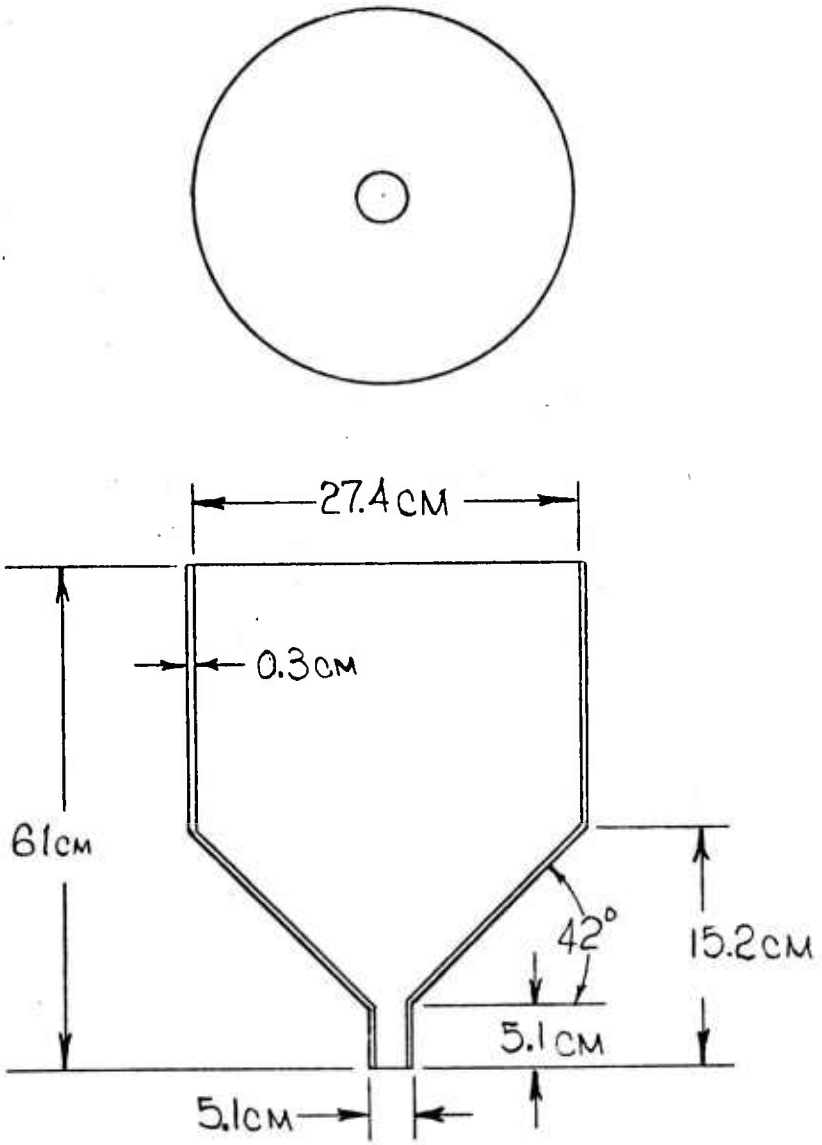


FIGURE 4. HOPPER FOR M-10 FLAKE

placed side-by-side and it would be necessary to determine a safe separation to prevent fire propagation should a deflagration occur in one of these receiving hoppers. A simplistic test program was devised wherein a single receiving hopper (donor) as seen in Figure 5, would be placed midpoint between two adjacent hoppers at some fixed safe separation distance. For purposes of economy and expediency, the two acceptor hoppers were replaced by simple witness trays. Both the donor hopper and the witness trays were filled with 2.3 kg of M-10 propellant and a fire was started at the bottom of the donor hopper.

Using this test setup, a series of exploratory tests was then conducted to determine the minimum safe separation distances to prevent fire propagation which was to be followed by a series of confirmatory tests at the predetermined safe separation distance. To simulate the most severe inplant condition, Tests 12 thru 23 were conducted wherein the test setup was placed inside a tunnel measuring 2.4 m by 2.4 m, hence the tunnel would act as a reflecting surface to direct burning material down into the witness trays.* Under the tunnel confinement conditions, it was determined that a safe separation in excess of 7.6 m would be required to prevent propagation. In tests conducted outside the tunnel, it was determined that a lesser separation would be required although the propagation was still occurring, on occasion, at a separation of 2.4 m. Table II lists all of the test data.

Continuing discussions with the ARRADCOM Project Engineer and with the user ammunition plants, Milan and Kansas AAP's, it was noted that the modernized plants would be using a hopper having a 3.0 meter extension stack above that 61 cm total height which was shown in the drawing of Figure 4. This new hopper configuration would thus place a more stringent requirement on the critical height limitations rather than the safe separation of the hoppers. Hence, this series of tests was discontinued in favor of those to be described in the next paragraph.

M-10 in Hoppers - Critical Height Determination

Realizing that M-10 propellant burns rapidly with a vigorous exothermic reaction, it was reasonable to assume that this propellant would transcend from a deflagration to a detonation given that it were stacked too high and that ignition would occur at the bottom of the tunnel configuration. Hence, a test program was begun to determine what that stacking height limitation would be to prevent a detonation should a deflagration be ignited. For the test series, the hoppers were held in the vertical position in an angle iron test stand, and an Atlas 300 electric match was used to cause ignition at the bottom of the funnel (Figure 6). A series of 39 tests was conducted, 18 of which were exploratory to determine the approximate critical height at which a deflagration would transcent into a detonation. The data given in Table III indicate that at stacking heights up to and including 31.8 cm, the M-10 propellant merely burned or produced a loud audible "bang" similar to an artillery piece firing blank ammunition. Under these conditions, however, no damage was done to the hopper and the reaction was judged to be a deflagration as opposed to a detonation. As the height of propellant contained in the hopper was increased from 25 cm to 45.7 cm this audible "bang" increased in intensity, and at 50.8 cm the hopper completely fragmented.

* 1.3 m distance top of tray to reflecting surface of tunnel top

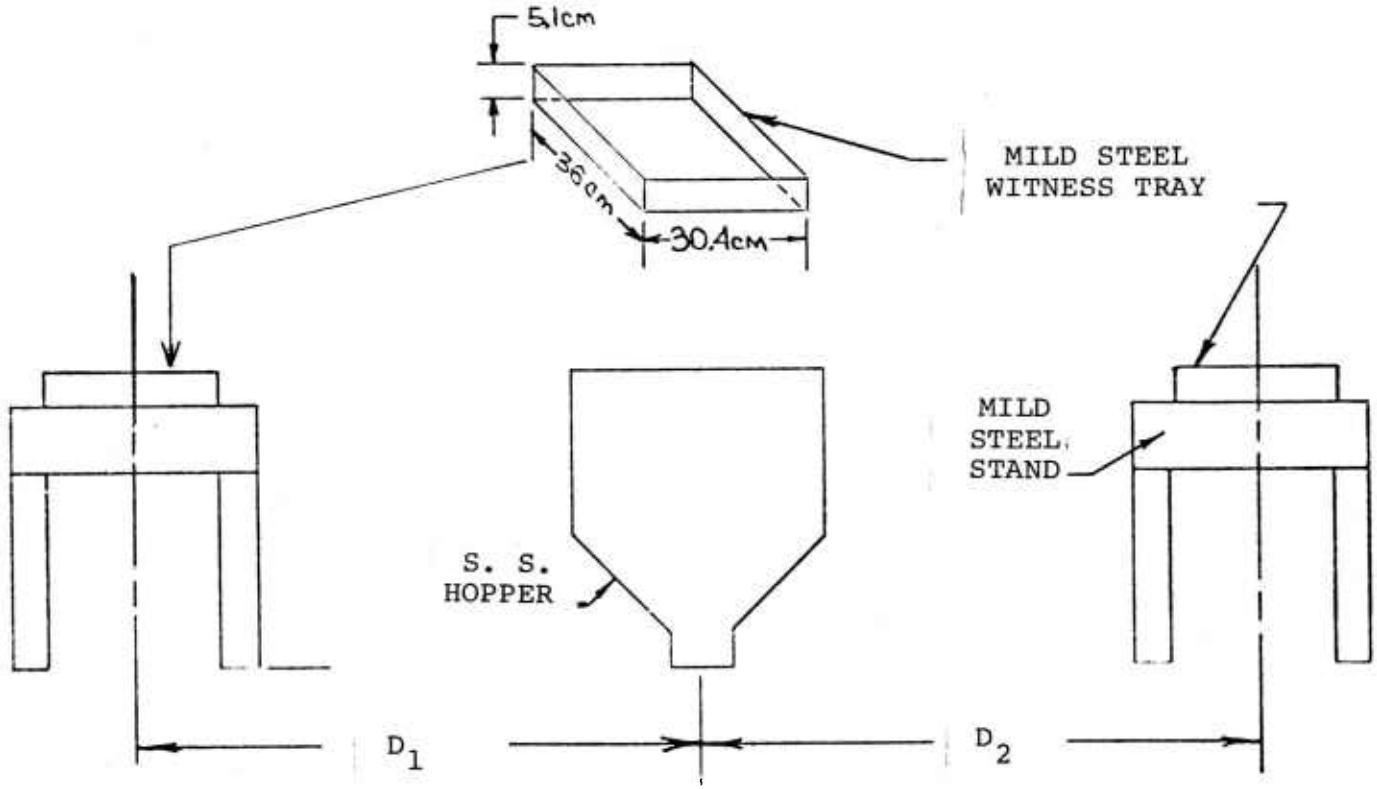


FIGURE 5. SAFE-SEPARATION TEST SETUP

TABLE II

SAFE SEPARATION OF M-10 LOADING HOPPERS

Test No.	Height of Propellant (cm)	Separation Distance (m)	Propagation		Remarks
			Acc #1	Acc #2	
1	12.7	1.8	No	No	4 sec. fire
2	12.7	0.6	No	No	4 sec. fire
3	12.7	0.6	No	No	3 sec. fire
4	12.7	0.6	No	Yes	4 sec. - both fires
5	12.7	0.9	No	No	4 sec. fire
6	25.4	0.9	Yes	Yes	2 sec. fire - 30 cm flame
7	25.4	1.8	No	No	2 sec. fire
8	12.7	1.8	No	No	3-4 sec. fire
9	12.7	1.8	No	No	3-4 sec. fire
10	12.7	1.8	No	No	3-4 sec. fire
11	12.7	1.8	No	No	3-4 sec. fire
12	12.7	1.8	No	No	3-4 sec. fire
13	12.7	1.8	Yes	Yes	Propagation Immediate
14	12.7	2.4	Yes	Yes	Propagation @ 1.5 sec. after donor
15	12.7	3	Yes	Yes	Propagation Slower than Test #14
16	12.7	4.6	No	No	
17	25.4	4.6	Yes	Yes	Propagation @ 1 sec. after donor
18	25.4	7.6	No	Not Used	Propagation @ 2 sec. after donor ignition
19	25.4	6.1	Yes	Not Used	
20	25.4	7.6	No	Not Used	
21	25.4	6.1	Yes	Not Used	Propagation @ 3 sec. after donor ignition
22	12.7	1.8	Yes	Yes	Propagation in hopper acceptor slower than tray
23	25.4	4.6	Yes	Yes	Propagation in hopper acceptor slower than tray
24	25.4	4.6	No	Yes	See note
25	25.4	4.6	No	No	See note

TABLE II (Continued)

Test No.	Height of Propellant (cm)	Separation Distance (m)	Propagation		Remarks
			Acc #1	Acc #2	
26	12.7	2.4	No	No	See note
27	12.7	1.8	No	Yes	See note
28	25.4	3	No	Yes	See note
29	12.7	1.8	Yes	Yes	
30	12.7	2.4	No	No	
31	12.7	2.4	No	No	
32	12.7	2.4	No	Yes	
33	12.7	2.4	No	Yes	
34	12.7	2.4	No	Yes	
35	12.7	2.4	No	No	
36	12.7	2.4	No	No	
37	12.7	2.4	No	Yes	
38 thru 44	12.7	3.7	No	No	

NOTES:

- Hopper is the donor, set between 2 acceptors. With the exception of tests 22 and 23 the acceptors were flat trays with 5.1 cm of M-10 propellant in each. In tests 22 and 23 one acceptor (no. 2) was another hopper filled to same level as the donor hopper.
- Tests 12 thru 23 were conducted in a tunnel 2.4 m x 2.4 m x 9.1 m with corrugated steel roof and walls.
- Tests 24 thru 44 were carried out under a canopy with a corrugated steel roof only. Hopper was located with the mouth located approximately 1.2 m from ceiling.
- Tests 30 thru 37 indicated a 25% occurrence of propagation. Due to wind conditions and the fact that only one acceptor propagated, distances were increased to 3.7 m.
- This testing discontinued per sponsor instructions and hopper modified to receive a 3 m extension. Testing continued under critical height phase of contract (see Table III, tests 19 thru 39).

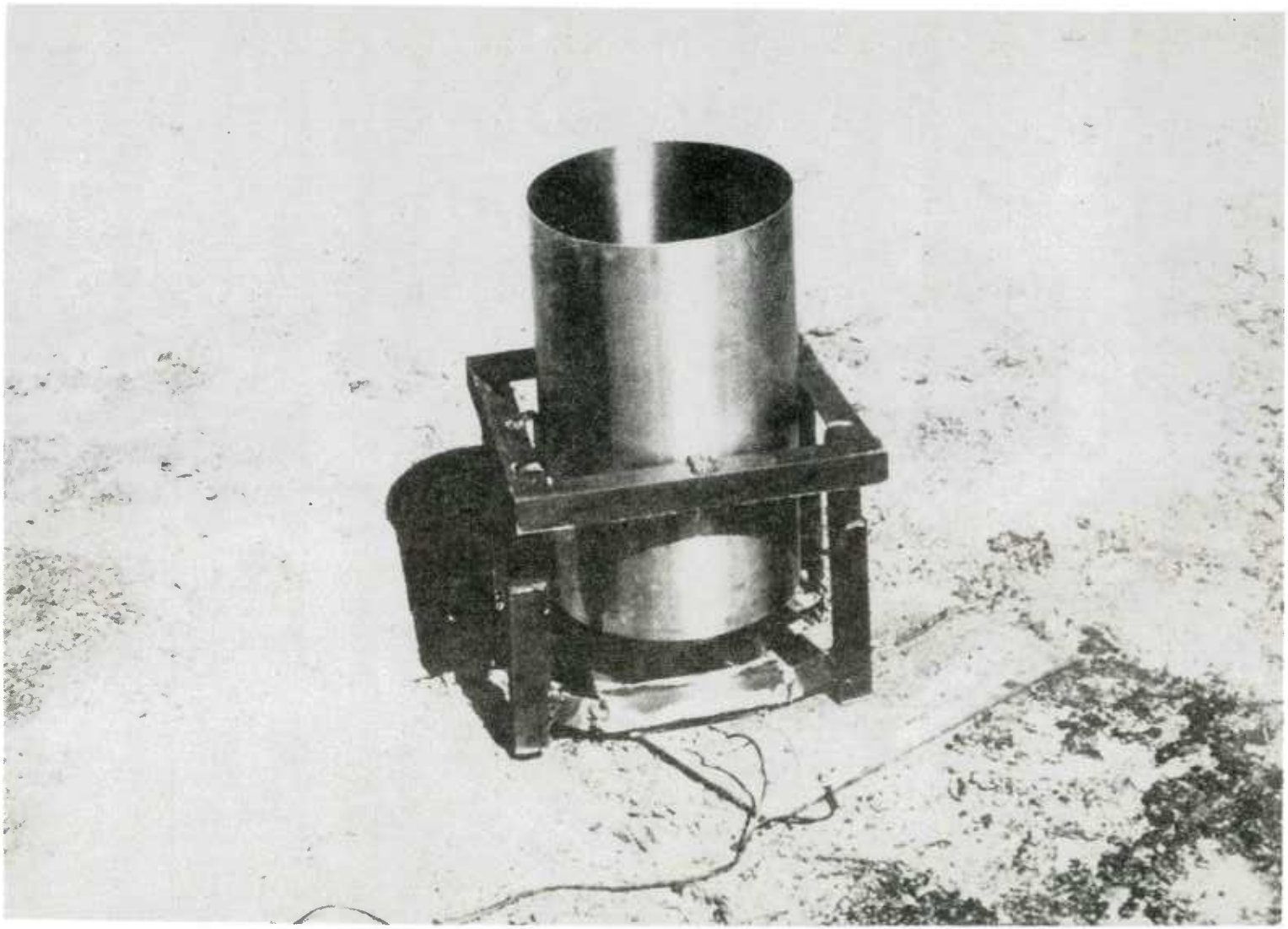


FIGURE 6. M-10 HOPPER IN TEST STAND

TABLE III.

CRITICAL HEIGHT OF M-10 PROPELLANT IN HOPPER

Test No.	Propellant Height (cm)	Propellant Weight (Kg)	Detonation	Pressure (kPa)	Description
1	12.7	2.3	No		1.8 m - 2.1 m high flame
2	25.4	7.8	No		Bright fireball eruption
3	38.1	14.2	?		"Bang" on ignition - unburned propellant ejected
4	43.2	17	?		"Bang" on ignition. Hopper neck crushed.
5	35.6	13	No		Bright fireball eruption
6	40.6	15.4	?		"Bang" on ignition - unburned propellant ejected
7	45.7	17.5	?		"Bang" on ignition - Hopper neck crushed.
8	50.8	20.4	Yes		Hopper fragmented.
9 thru 17	31.8	10.7	No	17.0	Sound similar to artillery piece firing blank ammunition. Eruption of flame from mouth of stack.
18	38.1	14.2	No		"Bang" on ignition - hopper separated from stack and hopper stand driven 4.4 cm into ground.
19 thru 39	31.8	10.7	No	17	Bright eruption of flame from mouth of stack - no damage to hopper or stack. No "bang" during fire

NOTES:

- All tests used M-10 propellant.
- Ignition at bottom of hopper using an Atlas 300 Electric Match.
- Tests 9 thru 39 were conducted with 3 m extension to the existing hopper.

At this point it was judged that a true detonation occurred. The relative damage to the M-10 hoppers is shown in Figure 7 for the 25 cm height and 45.7 cm height of propellant. Obviously, at 50.8 cm where the propellant detonated, the hopper was totally destroyed.

Based upon these exploratory tests, a safe critical height of 31.8 cm was judged to be adequate in preventing a detonation and Tests 19 through 39 were conducted to confirm this conclusion. During these tests, only a bright eruption of flame from the mouth of the hopper was observed and in no case was the audible "bang" heard.

In all of the tests series described throughout this report an attempt was made to conduct the tests under the most stringent simulated in-plant conditions. Hence, Tests 9 through 39 were conducted using a 3 m extension on the hopper which was shown in Figure 4. During the conduct of confirmatory Tests 19 through 39, pressure transducers were mounted at the midpoint of the stack extension and at the top. The test setup is shown in Figure 8. Pressure measurements made during the conduct of the confirmatory tests indicated that in no case did the pressure rise exceed 13 kPa, a pressure that was easily contained by a stainless steel stack.

In conclusion, the test series indicated that a safe critical height for M-10 propellant in the receiving hoppers is 31.8 cm, a height which will prevent a deflagration from transcending into a detonation.

M-10 After Loading in 81 mm M-205 Increments - Safe Separation

The next step in the process loading of M-10 propellant into the 81 mm increments is depicted in the test setup shown in Figure 9. Here each increment has been loaded while held in a fixture shown in the drawing of Figure 10. This drawing depicts the use of a barrier used to prevent propagation of fire from one mortar increment to the adjacent increment. The original processing fixtures did not include this barrier; however, the initial tests conducted in the test series indicate that a barrier would be necessary. A typical flame size from the burning of the donor 81 mm mortar increment seen in Figures 11 and 12 shows that propagation from one increment to the next will not occur if a barrier is used. The complete test series is listed in Table IV. Tests 1 through 33 indicate that a separation between fixtures of at least 25.4 cm is necessary to prevent propagation without a barrier between the increments. Tests 34 through 61 used a barrier between increments and this safe separation distance was reduced to 7.6 cm. The barrier used between the fixtures was 13.7 x 21.6 x 0.6 cm sheet of plywood.

The results of the test series clearly indicate that a safe separation of at least 25.4 cm is required if no barrier is used. Realizing that in order to maintain production rates at the ammunition plants this separation would be difficult to maintain, the use of a barrier is recommended in which case the safe separation distance can be reduced to 7.6 cm. At this separation distance each fixture will be touching the adjacent fixture.

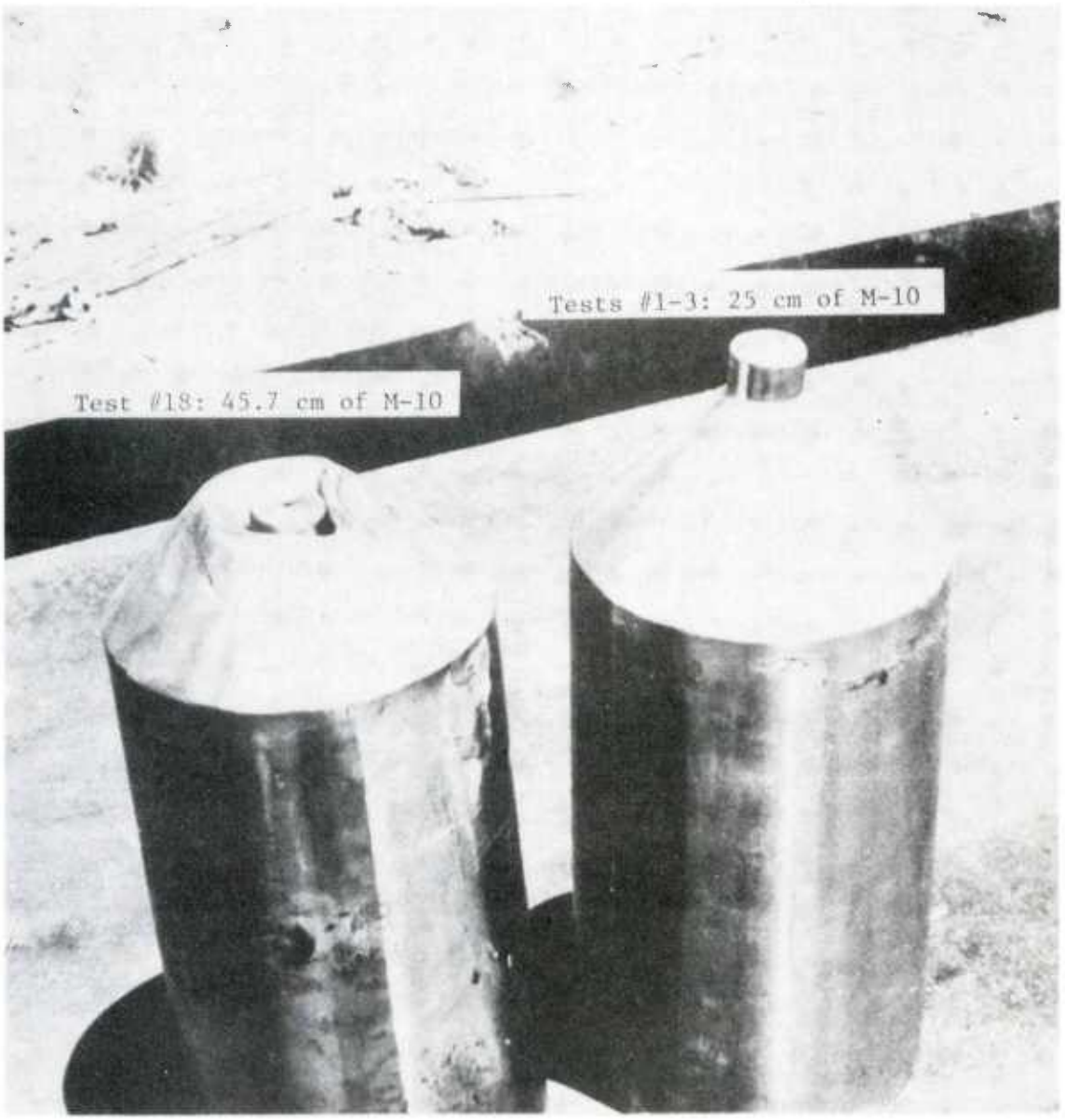


FIGURE 7. RELATIVE DAMAGE TO BASE OF M-10 HOPPERS

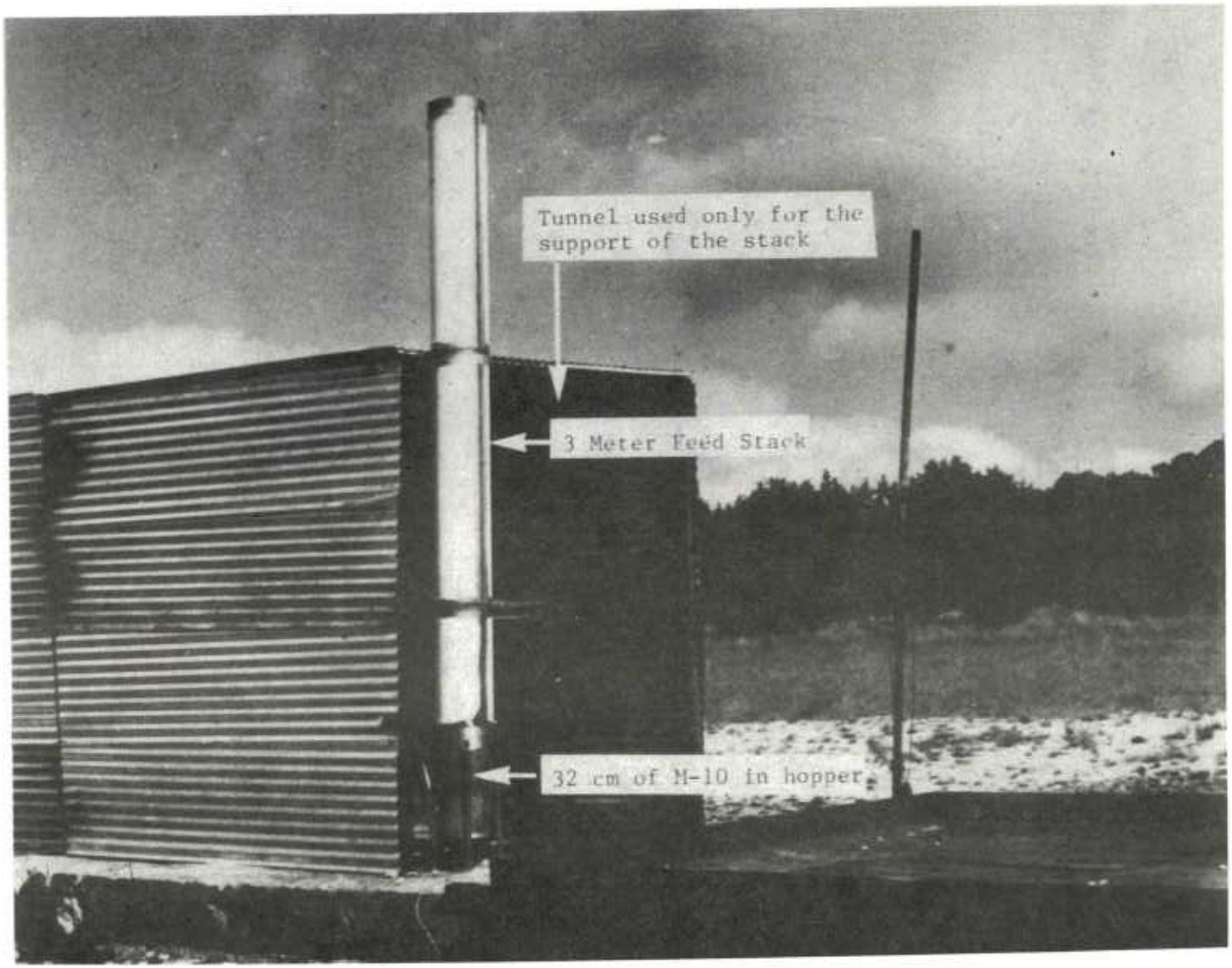


FIGURE 8. CRITICAL HEIGHT AND PRESSURE TESTS OF M-10 PROPELLANT

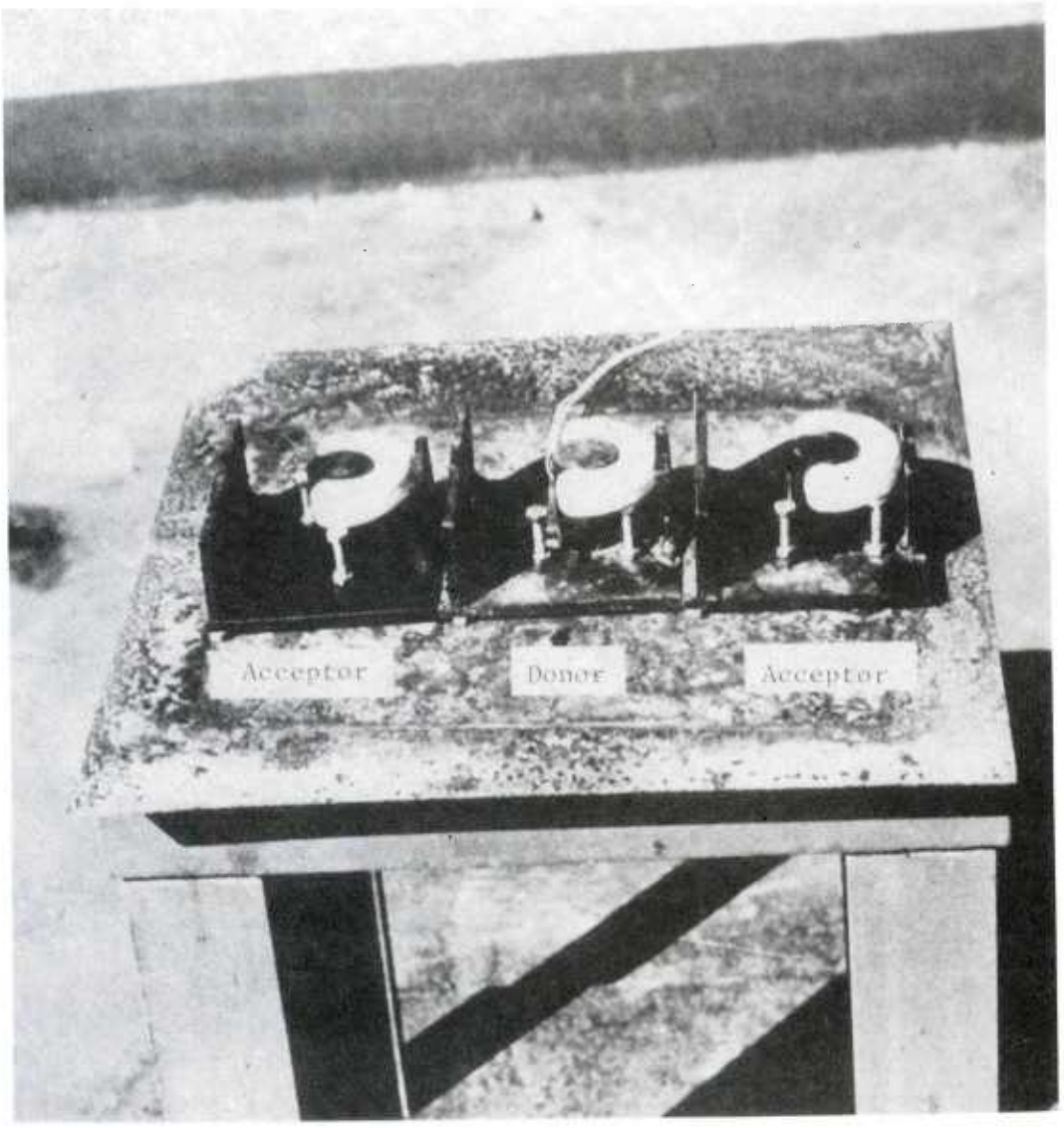


FIGURE 9. SAFE SEPARATION TESTS OF 81mm MORTAR INCREMENTS HELD IN FIXTURES

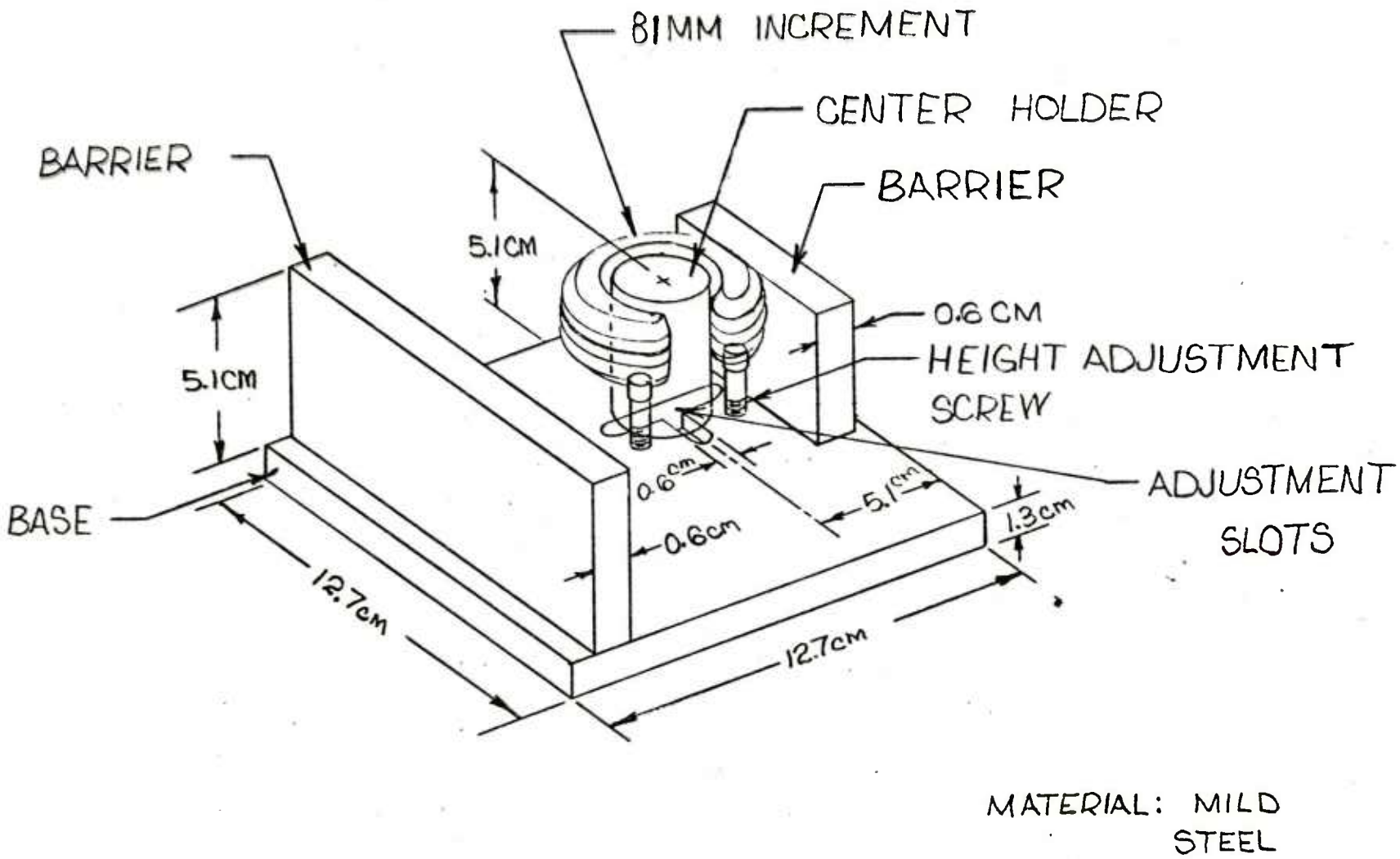


FIGURE 10. 81MM MORTAR INCREMENT TEST FIXTURE

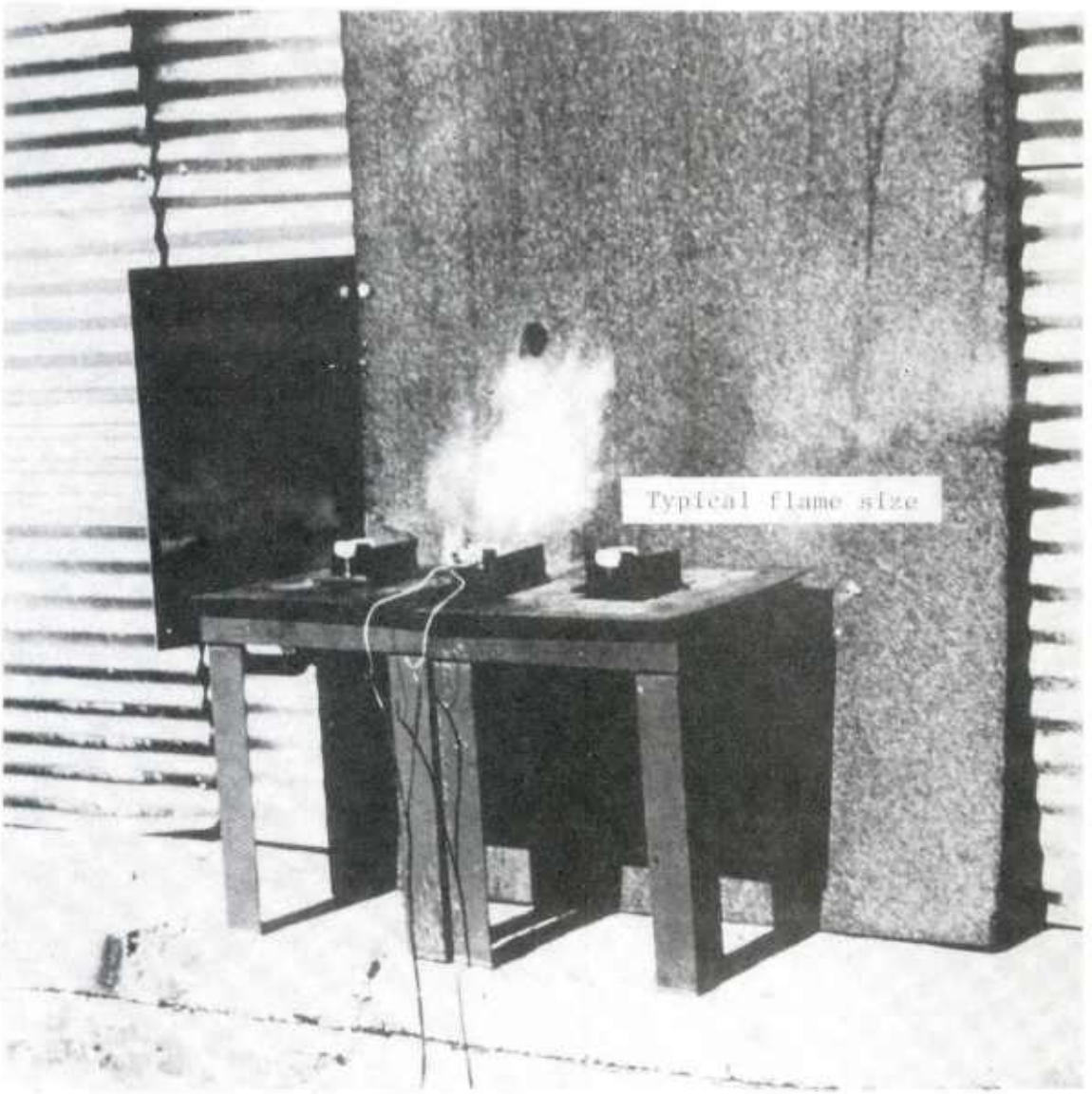


FIGURE 11. BURNING OF DONOR 81mm MORTAR INCREMENT

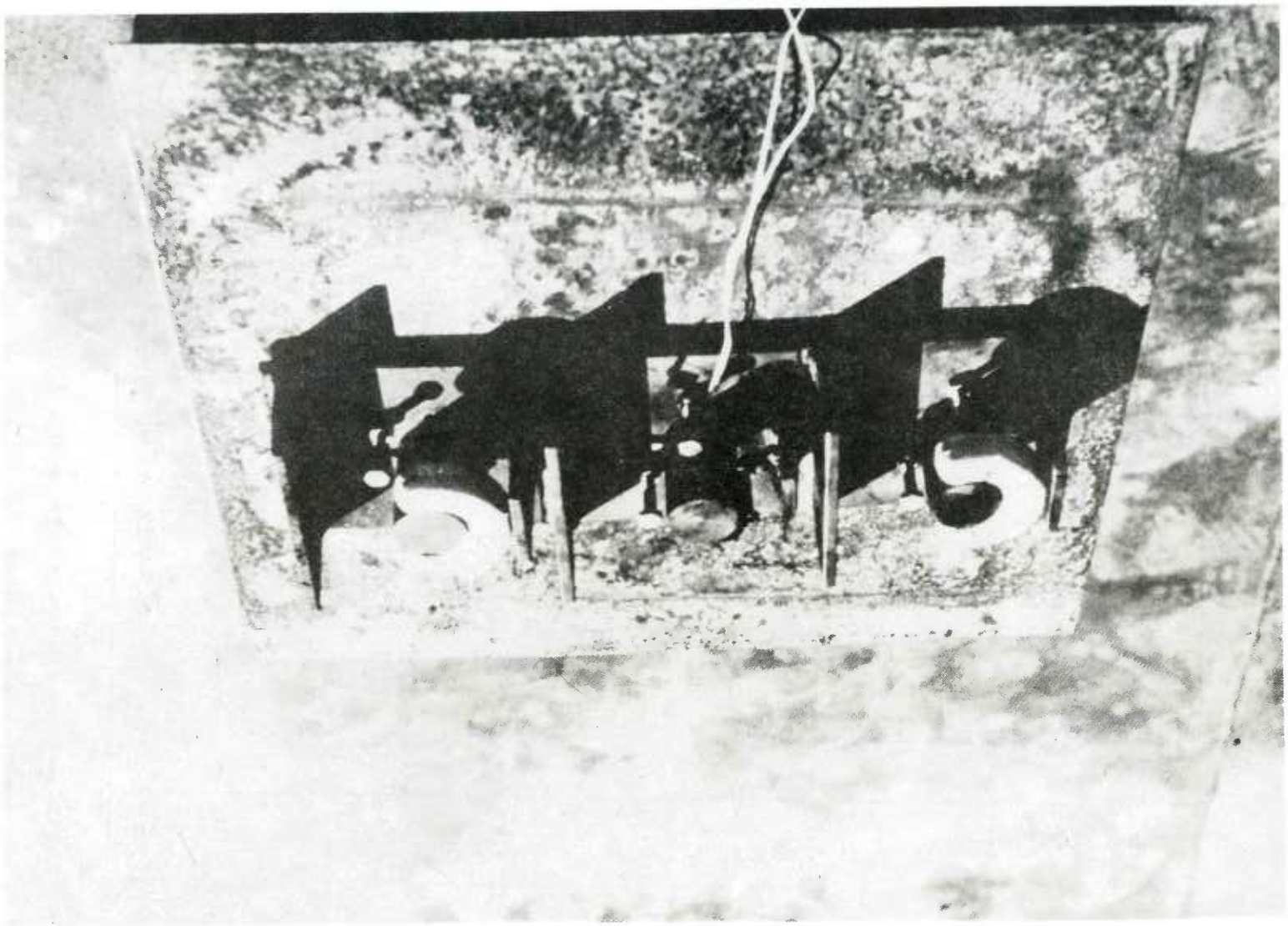


FIGURE 12. DONOR MORTAR INCREMENT BURNED, ACCEPTOR INCREMENT UNAFFECTED

TABLE IV.

SAFE SEPARATION
81mm MORTAR INCREMENTS

Test No.	Separation Distance (cm) Center-to-Center	Propagation		Description
		Acc #1	Acc #2	
1E	12.7	No	No	Slow burn ~ 2 sec
2E	7.6	No	Yes	Acceptor #2 ignited 2 sec after ignition
3E	12.7	No	No	Slow burn
4E	12.7	No	No	Slow burn
5E	12.7	No	Yes	Due to the ~2.5 sec delay of ignition and windy conditions on that particular day, wind was considered a factor.
6E	12.7	No	Yes	
7E	17.8	No	Yes	
8E	25.4	No	Yes	
9C	25.4	No	No	Installed a wind break
10C	25.4	No	No	Slow burn of donor
11C	25.4	No	No	Slow burn of donor
12C	25.4	No	No	Slow burn of donor
13C	25.4	No	No	Slow burn of donor
14C	25.4	No	No	Slow burn of donor
15C	25.4	No	No	Slow burn of donor
16C	25.4	No	No	Slow burn of donor
17C	25.4	No	No	Slow burn of donor
18C	25.4	No	No	Slow burn of donor
19C	25.4	No	No	Slow burn of donor
20C	25.4	No	No	Slow burn of donor
21C	25.4	No	No	Slow burn of donor
22C	25.4	No	No	Slow burn of donor
23C	25.4	No	No	Slow burn of donor
24C	25.4	No	No	Slow burn of donor
25C	25.4	No	No	Slow burn of donor
26C	25.4	No	No	Slow burn of donor
27C	25.4	No	No	Slow burn of donor
28C	25.4	No	No	Slow burn of donor
29C	25.4	No	No	Slow burn of donor
30C	25.4	No	Yes	Donor blew off fixture onto Acc #2
31C	25.4	No	No	Slow burn of donor
32C	25.4	No	No	Slow burn of donor
33C	25.4	No	No	Slow burn of donor

NOTES:
All tests were conducted by bottom ignition of the increment with an electric match.

No barrier between increments.

TABLE IV (CONTINUED)

SAFE SEPARATION
81mm MORTAR INCREMENTS

Test No.	Separation Distance (cm) Center-to-Center	Propagation		Description
		Acc #1	Acc #2	
34E	7.6	No	No	Barrier between fixtures - slow burn of donor.
35E	7.6	No	No	Same as Test 34E
36C	7.6	No	No	Same as Test 34E
37C	7.6	No	No	Same as Test 34E
38C	7.6	No	No	Same as Test 34E
39C	7.6	No	No	Same as Test 34E
40C	7.6	No	No	Same as Test 34E
41C	7.6	No	No	Same as Test 34E
42C	7.6	No	No	Same as Test 34E
43C	7.6	No	No	Same as Test 34E
44C	7.6	No	No	Same as Test 34E
45C	7.6	No	No	Same as Test 34E
46C	7.6	Yes	No	Donor blew off of fixture @ ignition and fell at the edge of the barrier and flame propagated around barrier to Acceptor #1.
47C	7.6	No	No	Same as Test 34E
48C	7.6	No	No	Same as Test 34E
49C	7.6	No	No	Same as Test 34E
50C	7.6	No	No	Same as Test 34E
51C	7.6	No	No	Same as Test 34E
52C	7.6	No	No	Same as Test 34E
53C	7.6	No	No	Same as Test 34E
54C	7.6	No	No	Same as Test 34E
55C	7.6	No	No	Same as Test 34E
56C	7.6	No	No	Same as Test 34E
57C	7.6	No	No	Same as Test 34E
58C	7.6	No	No	Same as Test 34E
59C	7.6	No	No	Same as Test 34E
60C	7.6	No	No	Same as Test 34E
61C	7.6	No	No	Same as Test 34E

NOTES: All tests were conducted by bottom ignition of the donor increment with an electric match.

A plywood barrier 13.7 cm x 21.6 cm x 0.6 cm was placed between the donor and each acceptor.

81 mm Increments in Storage Bin - Critical Height

The final process step for the 81 mm mortar increments is the release of the increment into a storage bin measuring 30.4 x 30.4 x 60 cm in height. The preferred stacking height in the storage bin was 45.7 cm which is sufficient to maintain the process rate required at the ammunition plant. Hence, a series of critical height tests as such was not conducted, but rather, a test evaluation consisting of 27 shots using only the single height of 45.7 cm. In all cases ignition was caused using an Atlas electric match placed at the bottom of the bin and stacking of the increments was in random fashion. Each bin contained approximately 500 increments. The results of the test series are given in Table V and indicate that in all tests there is a visual upheaval of the increments due to the generation of gases at the bottom of the bin. Following this upheaval, flame appeared and almost instantly grew to a large fireball which lasted approximately 10 seconds and subsided to just a small flame. Never was a detonation observed and never was any damage done to the storage bin.

It can be concluded from these tests that a storage bin height of 45.7 cm is a safe height and should a fire occur, this fire will not transcend into a detonation.

TABLE V.

HAZARD CLASSIFICATION OF
81MM MORTAR INCREMENTS IN STORAGE BIN

Test No.	Height (cm)	Description
1E	45.7	Very slow reaction - smoke for 1 or 2 secs. then flame and increments are projected into the air then burn.
2C	45.7	Same results as Test #1E.
3C	45.7	In Tests 3C through 27C there was a visual upheaval of increments from the bin at approximately 2 to 3 seconds after ignition. At the appearance of flame there is a large fireball which subsides to a fire plume from the storage bin. All tests showed only a fire - No detonation
4C	45.7	
5C	45.7	
6C	45.7	
7C	45.7	
8C	45.7	
9C	45.7	
10C	45.7	
11C	45.7	
12C	45.7	
13C	45.7	
14C	45.7	
15C	45.7	
16C	45.7	
17C	45.7	
18C	45.7	
19C	45.7	
20C	45.7	
21C	45.7	
22C	45.7	
23C	45.7	
24C	45.7	
25C	45.7	
26C	45.7	
27C	45.7	

NOTES: All tests were conducted in 0.6 cm wall thickness steel bin, 30.4 cm x 30.4 cm x 60 cm

- Ignition for all tests were by electric match in an increment at the bottom of the bin.
- Stacking of increments was random, approximately 500 increments per test.

M-1 Propellant Loading With Base Pad and Center Core Igniters for 155 mm and 20.3 cm Howitzers

The Project Manager for the Plant Modernization Program urgently requested that the Manufacturing Technology Division, Special Technology Section, of ARRADCOM investigate the possible reclassification of the igniter production lines at the Indiana, Lone Star, Kansas and Iowa AAP's from a 1.1 mass detonation hazard to a Class 1.3 fire hazard. These igniter lines are producing black powder and clean burning igniters (CBI's), base igniters and black powder center core igniters for use in the 155 mm and the 8-in. gun rounds. This urgency arose when expensive modifications would have to be made to the existing facilities if the bagged igniter lines remained a Class 1.1 operation.

After the fabric bags are loaded with their igniter mix, they are transported via steel roller conveyors to a point in the processing line where they are in turn loaded with M-1 propellant. At any point in this processing activity a fire could occur and could result in either the mass detonation of boxed bag igniters and/or drums transporting the M-1 propellant. It was necessary to determine, therefore, whether the boxes of igniter bags would detonate on ignition, and similarly whether drums containing 68 kg of M-1 propellant would detonate or simply burn should ignition occur. A series of tests was conducted to determine these two vital plant design criteria and the results are described herein.

Safe Separation of M-1 Receiving Drums

At the load assembly and pack (LAP) U.S. Army Ammunition Plants, M-1 propellant is received via either truck or rail and transferred on to roller conveyors which transport the propellant to the loading activity. The drums are transported from the receiving building through a tunnel ramp conveyor, a tunnel which offers restriction or confinement to the fire should ignition occur at any point down the tunnel ramp. A typical view inside the ramp is seen in Figure 13 wherein the drums are transported at a nominal safe separation distance at an elevation of one to two meters above the floor height. At the receiving dock the shipping lids are removed from cardboard drums and a lever arm which is part of the drum dumping mechanism holds a lightweight lid on the top of each drum. For the test series conducted herein, thin sheets of aluminum were used to simulate the lids and the cantilever weight of the dumping mechanism was simulated with the use of steel weights placed on top of the aluminum lids.

Since the weather protective tunnel provides confinement to a fire or explosive event and also provides a deflecting surface, thus assisting possible propagation, it was important to simulate the true in-plant environment and to conduct the tests in a tunnel environment. Hence, a tunnel was constructed of an angle iron frame measuring 2.4 m x 2.4 m x 10 m, and this frame was covered with 29 gage corrugated steel walls and roof. The interior walls of the tunnel were lined with 1.6 cm sheet rock. The donor drum was ignited at the bottom in all cases using an Atlas-300 electric match with a 2 gram black powder booster.

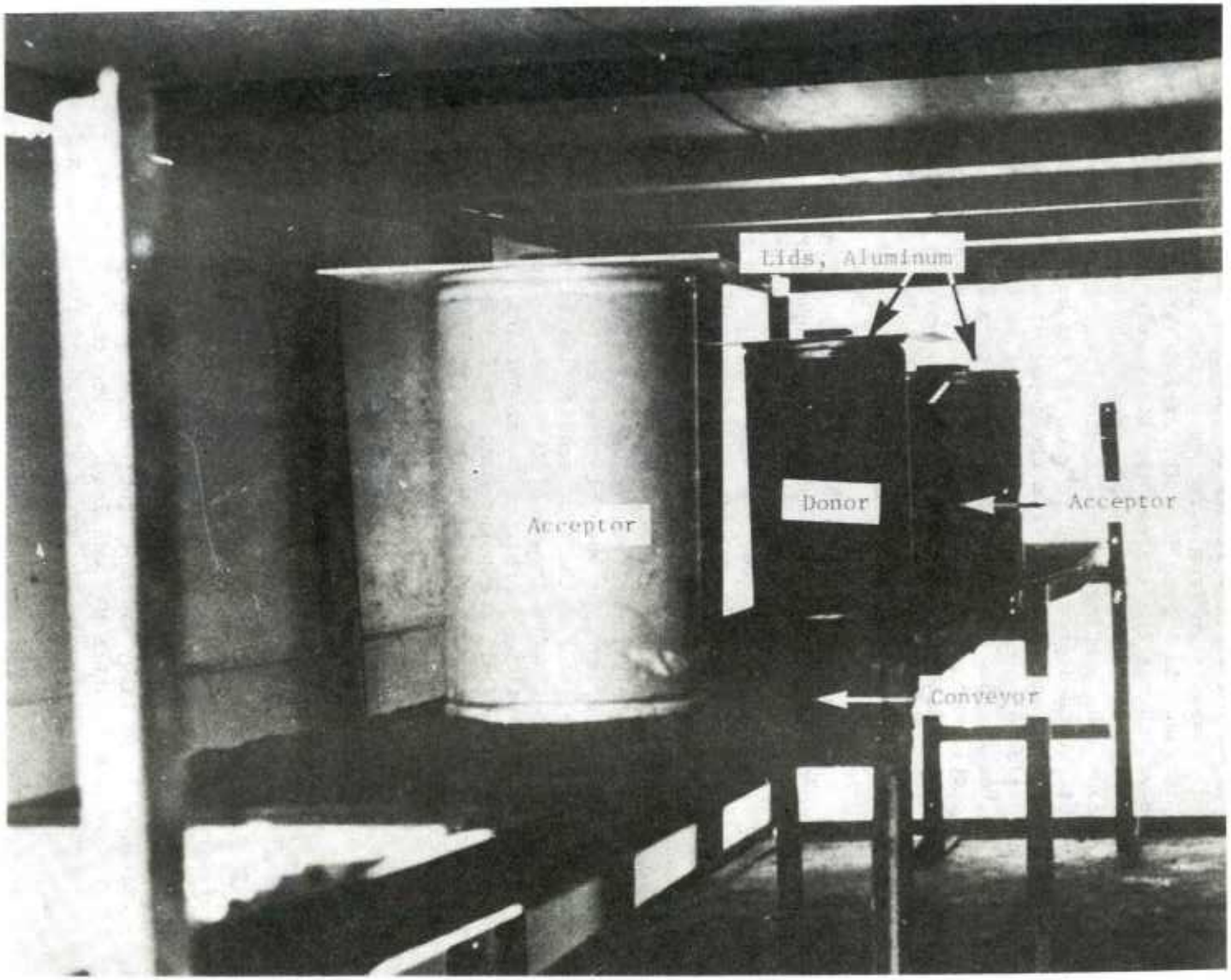


FIGURE 13. TEST #1 AT 2.4 m SHOWING DRUMS WITH LIGHTWEIGHT ALUMINUM LIDS

The results of a typical test are shown in Figure 14 and two conclusions are immediately apparent after a review of the high speed camera (400 fps) films. Selected frames taken from a record wherein propagation occurred to both acceptors is shown in Figure 15. The fire in the donor drum generated sufficient gases to thrust the lid and the steel weight through the roof of the building, and, through a recoil action, forced the base of the drum in a downward direction thus bending and collapsing the roller conveyor. The intense fire which ensued propagated to each of the acceptor drums which had been placed at a distance of 2.4 m from the donor drum. It was also apparent that detonation did not occur in either the donor or the acceptor drums. The film clips reveal that the fire in the acceptors was started by heat and/or sparks getting under the lightweight lids, thus igniting the acceptor propellant. Hence, Test No. 3 shown in Figure 16 was run in the open air at the same separation distance of 2.4 m. Here propagation did not occur when heavy weights were used to hold the lids in place.

Returning into the tunnel confinement as shown in Figure 17, Tests 4 through 11 as noted in Table VI were made at varying separation distances and with pressure gage instrumentation to determine the pressure rise within the tunnel confinement. In all tests a hole was punched open in the roof in an area immediately over the donor drum of M-1 propellant. In no case, however, did propagation to either of the acceptors occur. The pressure gage readings ranged from 7 to 14 kPa which was insufficient to cause any additional damage to the tunnel. The safe separation confirmatory Tests Nos. 13 through 27 were fired in a tunnel confinement at a separation distance of 4.6 m as seen in Figure 18. For each of these tests, the lids were held in place with a 2.3 kg weight and the test results listed in Table VI indicate that propagation did not occur in any of the tests. The cardboard drums provide adequate insulation to protect the propellant for the brief (approximately 4 seconds) fire exposure and the 2.3 kg weights effectively sealed the lid such that no sparks or heat are transmitted to the propellant through this opening.

The test series resulted in the conclusion that a cardboard drum containing 68 kg of M-1 propellant will not detonate when ignition occurs within the drum. It was also determined that, although an intense fire did result, propagation of that fire can be prevented if a separation distance of 4.6 m is maintained on the conveyor line.

Safe Separation of Boxed Igniters

Under ARRADCOM Project 2610, the 155 mm and 8-in. propellant charge igniters posed a potentially serious problem during their transport to the point in the processing where M-1 was loaded into the fabric bags. These igniters are transported in plastic boxes and are of two types: a 140 gram black powder base pad designated M1 or M2, which was contained at the bottom of a 0.014 cubic meter empty cotton bag, and the second igniter was an 85 gram, clean burning igniter (CBI) designated either M3A1 of M4A2. This latter igniter contains single base flaked M-10 propellant which is almost pure nitrocellulose and contains a trace of potassium sulfate to reduce flash.

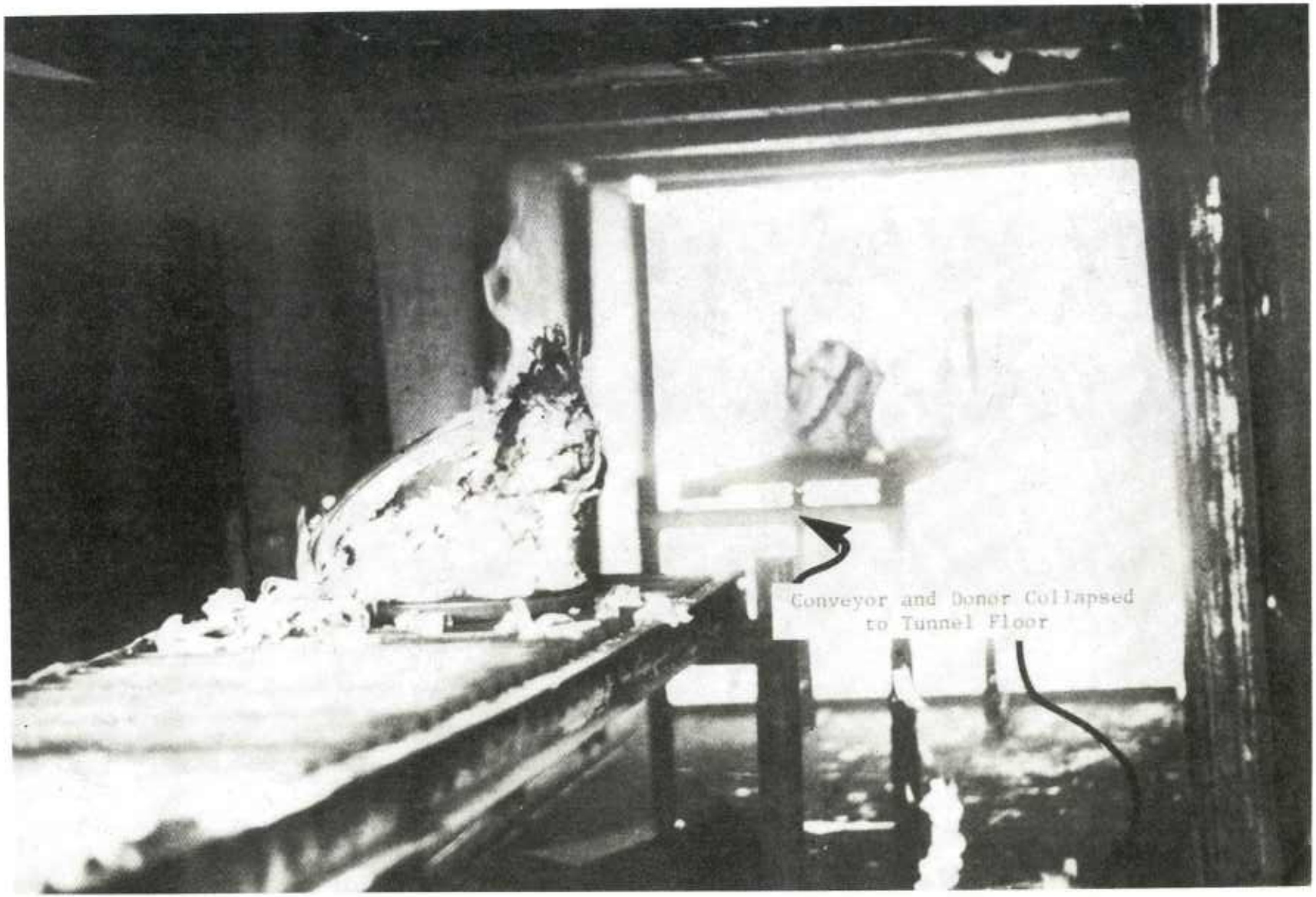
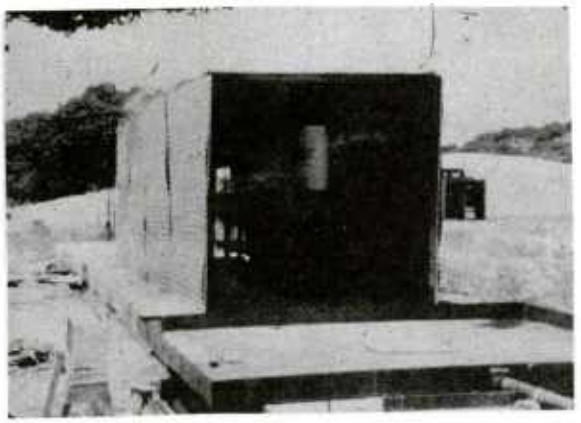
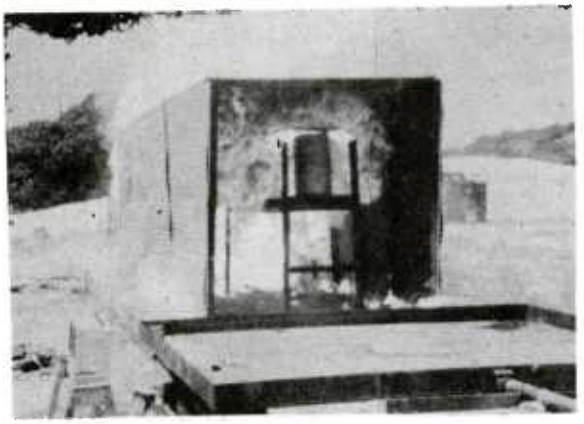


FIGURE 14. RESULTS OF TEST #1 AT 2.4 m DONOR FIRE PROPAGATED TO BOTH ACCEPTORS

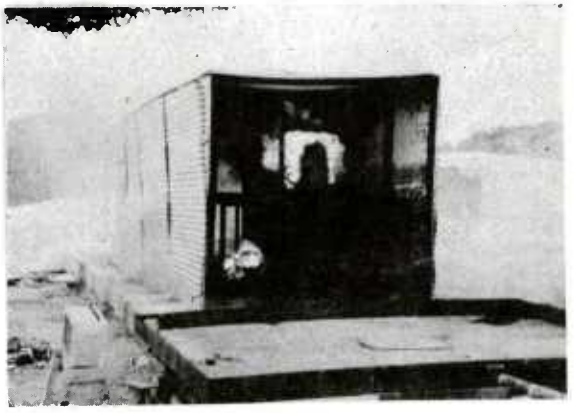
1. Before Ignition



2. Donor drum burns on the floor while fire propagates to the acceptor under the lid



3. Donor fire recedes while acceptor fire grows



4. Acceptor fire bursts out of tunnel

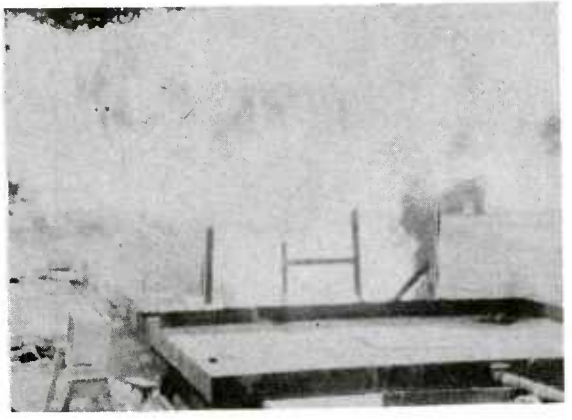


FIGURE 15. FILM CLIPS SHOWING PROGRESS OF FIRE PROPAGATION

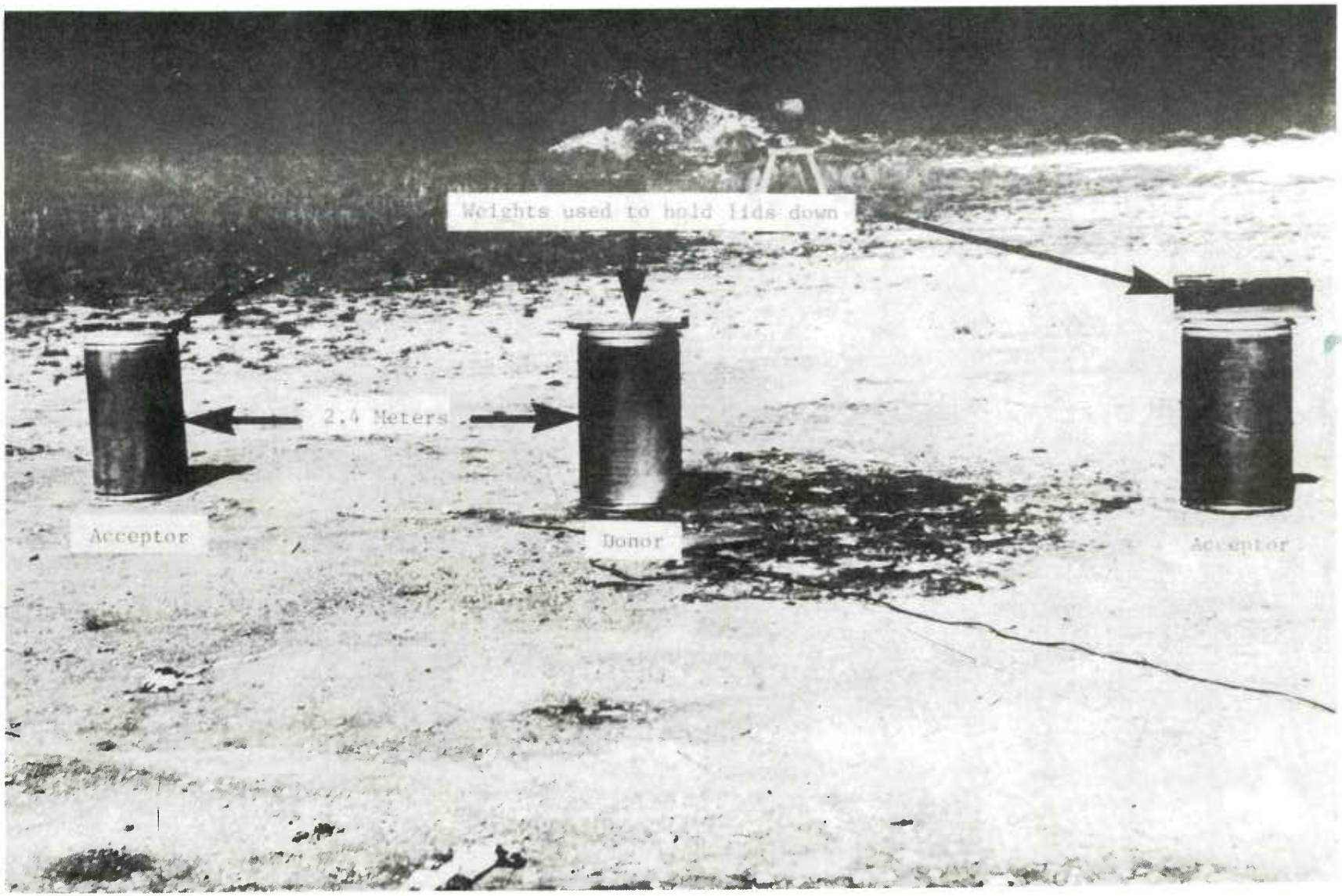


FIGURE 16. SAFE SEPARATION OF M-1 PROPELLANT DRUMS
TEST NO. 3

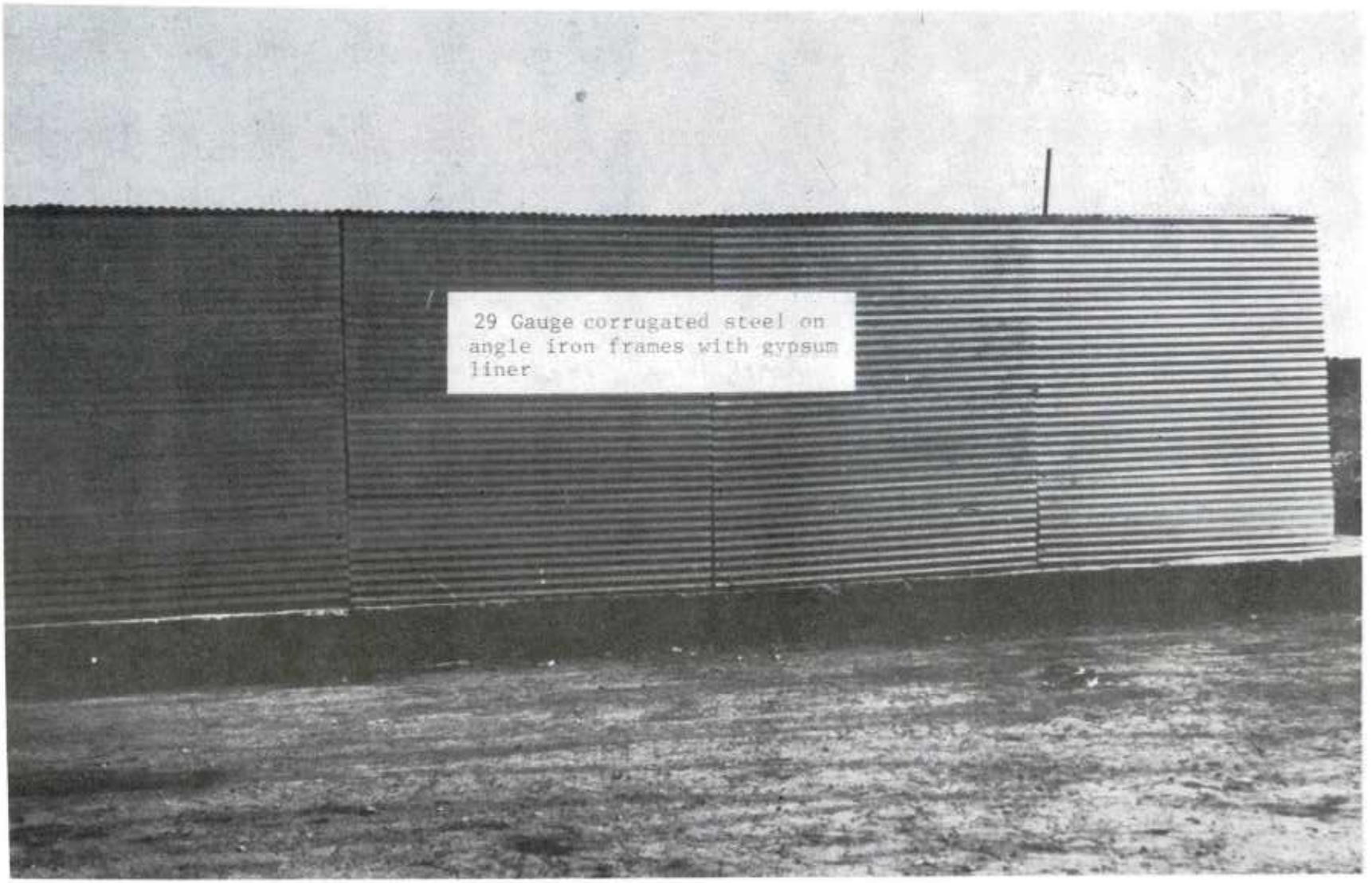


FIGURE 17. SIDE VIEW OF TUNNEL RAMP

TABLE VI

SAFE SEPARATION OF M-1 PROPELLANT DRUMS

Test No.	Separation Distance (m)	Propagation		Temp. (°C)
		Acc #1	Acc #2	
1	2.4	Yes	Yes	260
2	4.6	Yes-7 sec.	Yes-7 sec.	--
3	2.4	No-Heavy Lid	No-Heavy Lid	--
4	7.6	No	--	--
5	4.6	No	--	--
6-11	Pressure gages check-out shots			--
12	4.6	No	Not Used	--
13	4.6	No	No	--
14	4.6	No	No	--
15	4.6	No	No	--
16	4.6	No	No	--
17	4.6	No	No	--
18	4.6	No	No	--
19	4.6	No	No	--
20	4.6	No	No	--
21	4.6	No	No	--
22	4.6	No	No	--
23	4.6	No	No	--
24	4.6	No	No	--
25	4.6	No	No	--
26	4.6	No	No	--
27	4.6	No	No	--

NOTES:

- Fiberboard drums contained 68 kg, MP propellant.
- All drums were placed on roller conveyor, 1.2 m above ground.
- Tunnel was 2.4 m x 2.4 m x 0.5 m angle-iron covered with 29 ga corrugated steel walls and roof. Interior walls were covered with 1.6 cm sheetrock.
- Donor drum ignited at the bottom using an electric match w/2 gram black powder booster.
- Tests 3-27 used weighted lids

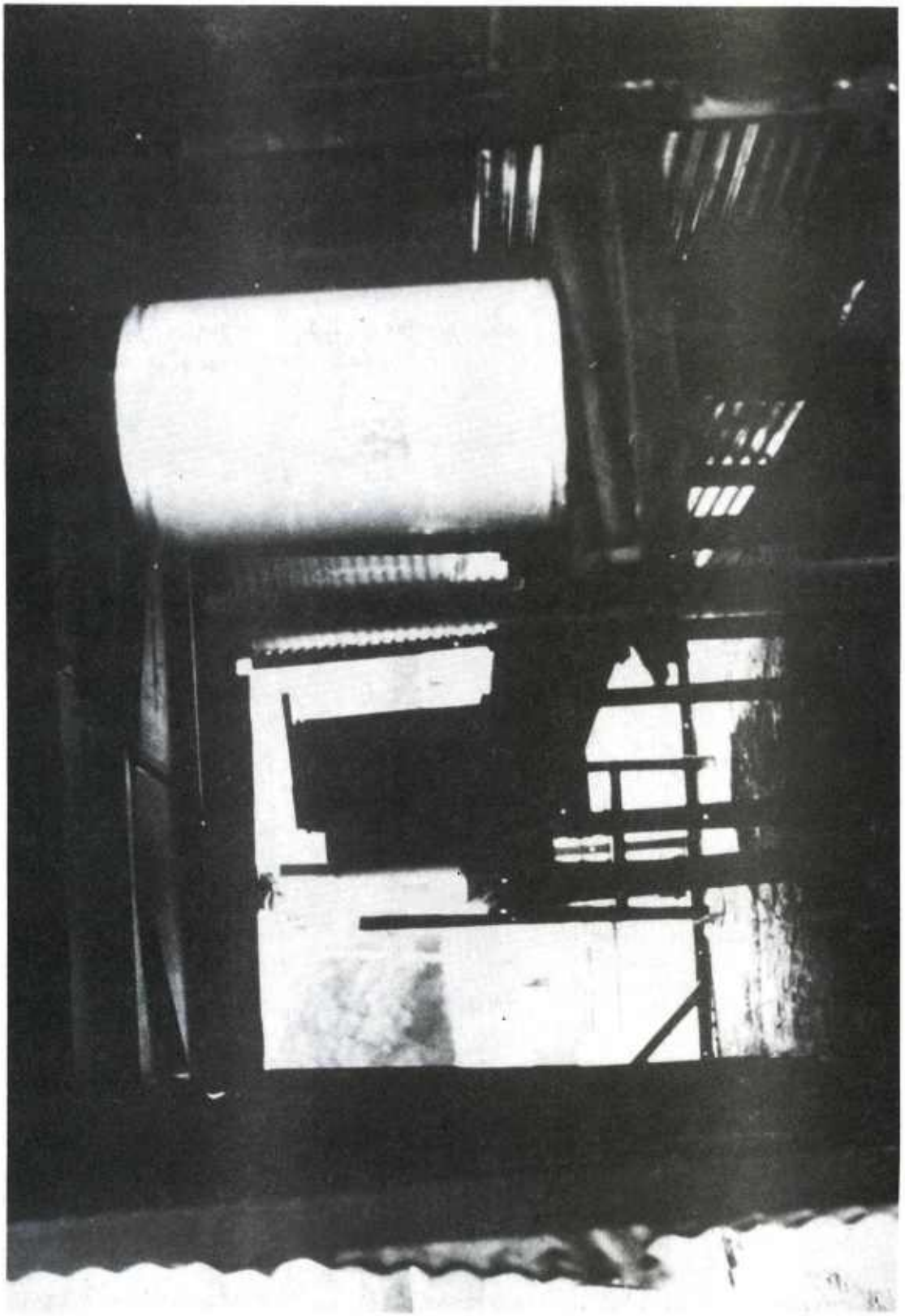


FIGURE 18. SET-UP OF TESTS 13-27 WITH WEIGHTED DRUM LIDS AT 4.6m SEPARATION

Under ARRADCOM Project 2694, the center core igniter for the 8-in. gun, designated M188 or M203, was tested. This center core igniter contains 142 grams of black powder in a tube configuration measuring approximately 2.54 cm in diameter by 30 cm long.

All of the tests consisted of placing on a simulated conveyor a box containing a number of the designated igniters. This box, designated as the donor charge, was placed in the center of two adjacent boxes, placed in contact to or at some distance from, the donor box. These two adjacent boxes were designated as acceptor charges; hence, each test firing consisted of two evaluations of the possible propagation of the fire from the donor box to the acceptor box.

The boxes used for the tests were Nestier plastic reusable containers. For the base pad and CBI igniter evaluations, the Nestier model 09-220 box measuring 61 cm x 61 cm x 26 cm was used. Since the center core igniters were larger in size, for these tests the Nestier Cart Pak model 09-520 box was used. This latter box measured 69 cm x 43 cm x 32 cm. Each of these boxes was placed on a pedestal to simulate the elevation of a conveyor line, and depending upon the test, was placed either adjacent to or set at some distance from the donor box.

For the conduct of the tests, ignition of the donor box was achieved using an Atlas electric match, which was placed inside one of the individual igniters and set at the very bottom of the donor box.

The most important determinations to be made from the hazard classification tests is the determination of whether a small fire ignited in the donor box could transcend into a mass detonation and could that detonation be propagated along a conveyor line. This determination was made during the course of the tests, first by a visual and audible monitoring of each test firing and secondly, through the use of transducers and temperature recording pellets to monitor any pressure or temperature rise occurring during the event. Also of importance was the observation of whether a detonation or fire could be propagated to each of the acceptor boxes. Determination of this occurrence was monitored in the same way as the donor events were monitored. For the test evaluation of each of the three igniter types, a brief series of exploratory shots was fired in which two basic determinations were made; first, did a detonation occur and secondly, if a detonation did not occur, what would be the minimum safe separation to prevent propagation of the fire from the donor tote bin to the acceptor tote bin. Following these exploratory test shots, and assuming that indeed no detonation did occur, a series of approximately 25 confirmatory tests was conducted. Since two acceptor bins were used for each test, these 25 test firings would then constitute a total of 50 evaluations. The results of the test firings are presented in the following discussion for each type of igniter which was evaluated.

Figure 19 is a photograph of 50 black powder igniters in the transport box being prepared for test and Figure 20 illustrates a typical test set-up. Each container was placed on a pedestal set a given distance apart and teletemp monitors were used to record the ambient temperatures nearby to the ensuing fire. The gases generated on ignition result in the upheaval of the bags

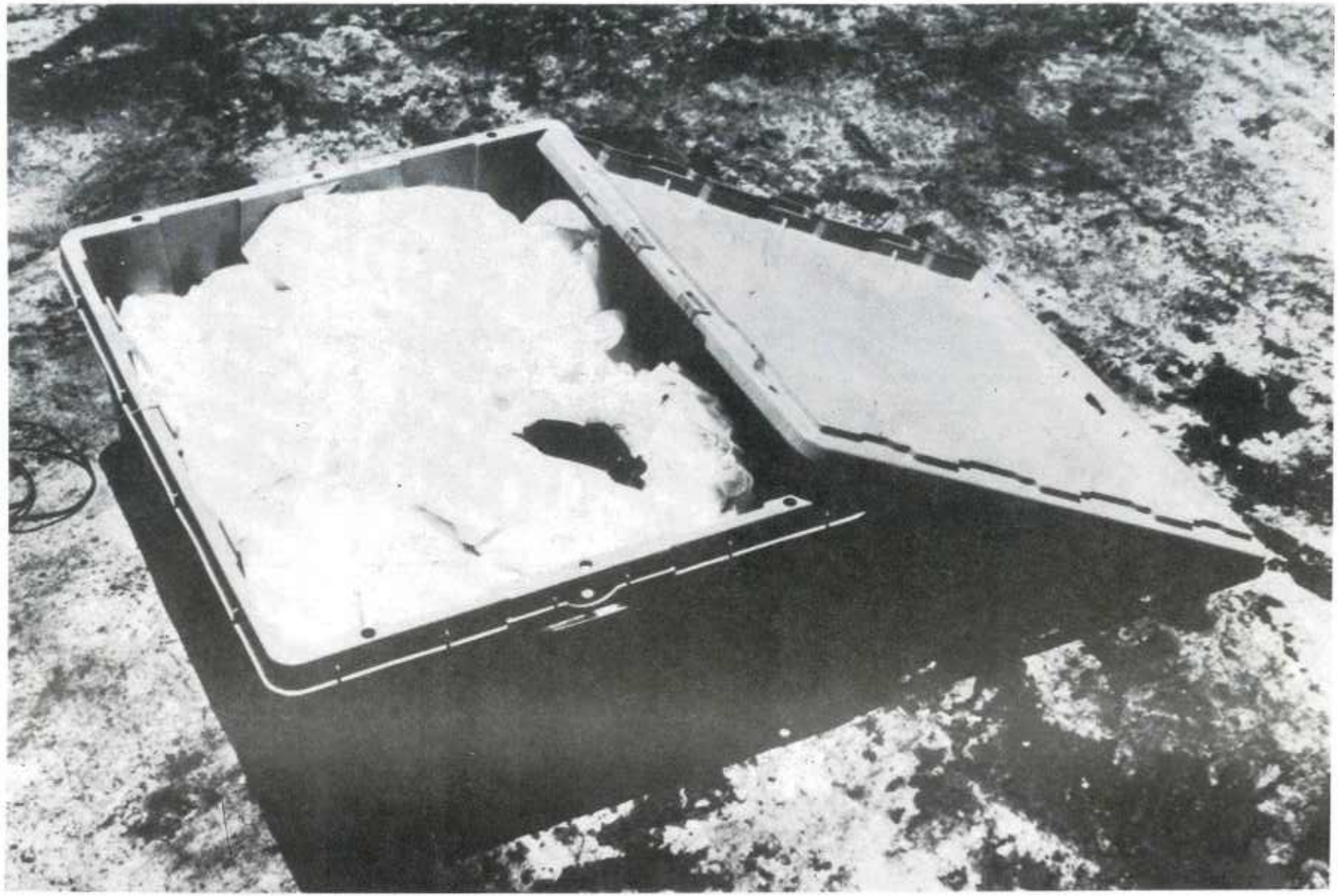


FIGURE 19. PROJECT 2610 - 50 BLACK POWDER IGNITERS IN TRANSPORT BOX PRIOR TO TEST

FIGURE 20. DETERMINATION OF SAFE SEPARATION PROJECT 2610 - BASE PAD IGNITERS

which bursts the top off of the plastic box and throws the burning propellant bags over the surrounding area (Figure 21). These bags could, and in some instances did drop on top of the acceptor boxes. This burning bag could melt the plastic lid of an adjacent box and eventually result in the propagation to that adjacent container. In Table VII, the results of all of the tests with the black powder base igniters are presented. Here it can be seen that six exploratory test firings were conducted, and these were followed by a total of 24 confirmatory tests. Since exploratory Test No. 9(e) was identical to the confirmatory tests, this also constituted a confirmatory test firing for a total of 25 firings or 50 test evaluations. Examining the six exploratory tests, one can see that the separation of the donor and acceptor boxes varied from 0 meters (edges of the boxes were touching) to 3.0 meters separation. The third column of Table VII is entitled "Box Lid and Handholds". This title refers to the condition of the box during the test, since it was recognized as early as the first or second shot that no detonation was occurring, and that the propagation of the fire from donor to acceptor would be caused strictly by the direct contact of a flame source with additional flammable material. It was observed that, on ignition of the donor tote bin containing the black powder igniters, very rapid burning occurred, and because of the gas which was generated, the lid of the donor box would be pushed open and in some cases would push the lid off of the acceptor box. It was also observed that fire could get through the handhold of the donor box and into the handhold of the acceptor box. Each of these problems was readily solved by simply taping the handhold shut and by bolting the lids closed. Hence, all of the confirmatory shots were fired with the boxes bolted and taped.

Still referring to Table VII, column 4 presents the results of the test firings in terms of propagation of fire into each Acceptor No. 1 or Acceptor No. 2. Considering the results of the confirmatory shots (including exploratory Shot 9), in only eight cases out of the 50 tests did a fire propagate from the donor to the acceptor, and in only two instances was simultaneous propagation observed. The term "simultaneous" in this context means that the fire was propagated in a period of time of less than approximately five seconds. In all other cases, propagation took from two to five minutes and was caused by a burning bag falling on the lid of the acceptor tote bin and eventually burning its way down to the igniter bag.

It has been stated that in no case did a detonation of either donor or acceptor tote bin occur. Pressure transducers which were placed 0.6 m from the donor tote bin indicated no pressure rise, thus verifying that a detonation did not occur. Tempil pellets placed at a distance of 1.5, 3.0, 4.5 and 6.0 m from the source of the fire in the donor tote bin indicated that temperatures as high as 190° C down wind of the fire could be obtained, but that this thermal rise fell off very rapidly with distance and was down as low as 80° C at 4.5 m and was negligible at greater distances.

The test results for the hazard classification of the clean burning igniters (CBI) are shown in Table VIII. Here the results of five exploratory tests and 24 confirmatory tests (Shot 17(e) is also considered as a confirmatory test) indicate that in each and every case a detonation did not occur. Since each shot constitutes two tests, in only six instances out of 50

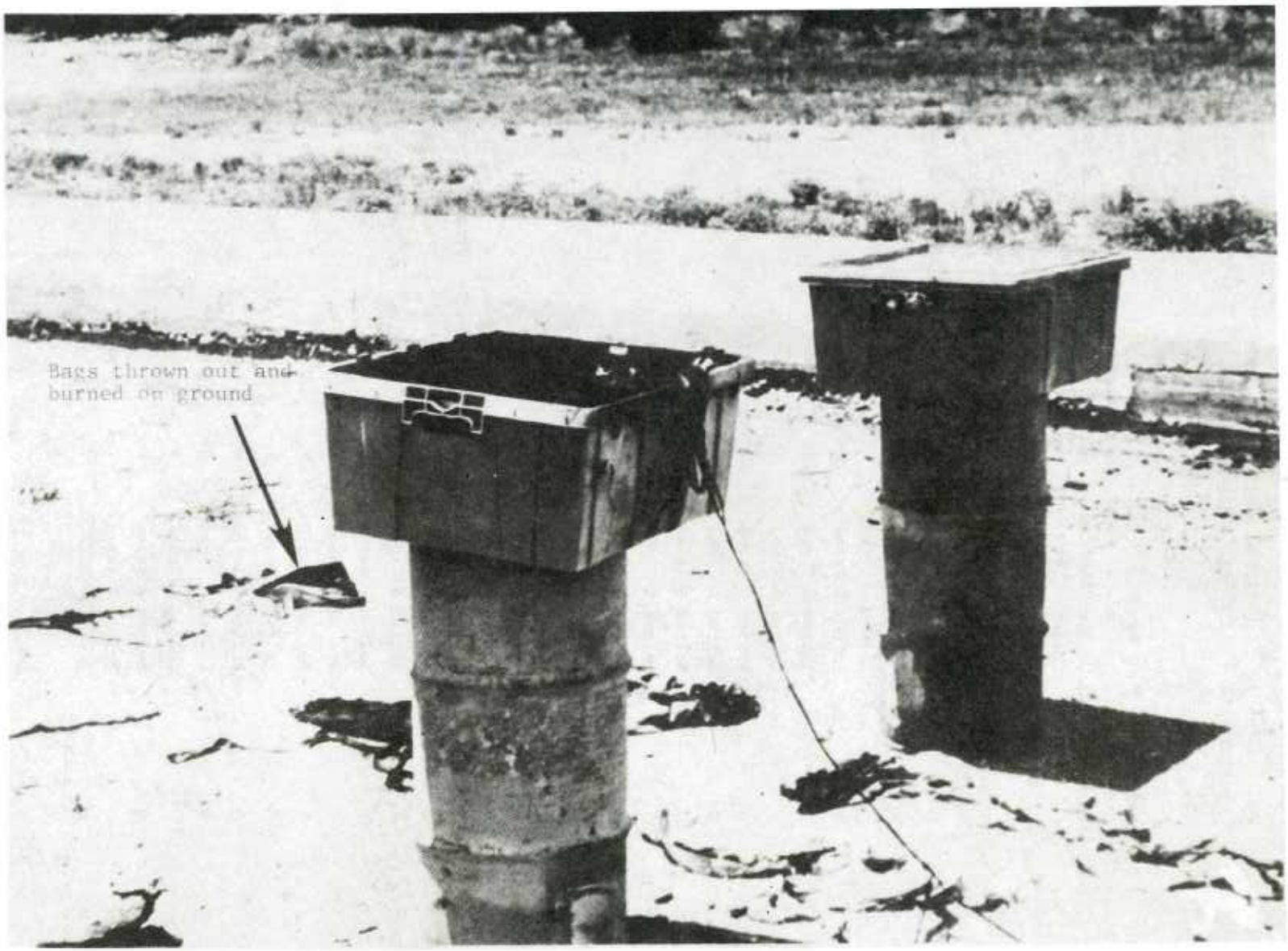


FIGURE 21. DONOR BOX OF IGNITERS BURNED WITH NO PROPAGATION

TABLE VII
HAZARD CLASSIFICATION TESTS
PROJECT 2610 - BLACK POWDER BASE IGNITERS* FOR 8"(20cm) HOWITZER

SwRI Test No.	Box Separation (Edge-to-Edge) (meters)	Box Lid and Handholds	Propagation Acc #1	Propagation Acc #2	Remarks
1E	0	Closed only	Yes	Yes	Simultaneous propagation
2E	3	Closed only	No	No	
3E	1.2	Closed only	No	No	
4E	0.3	Closed only	Yes	No	Simultaneous propagation
9E	0	Bolted & Taped	No	Yes	5 min. to propagation
15E	0.3	Bolted & Taped	No	No	
18C	0	Bolted & Taped	No	No	
19C	0	Bolted & Taped	No	No	
20C	0	Bolted & Taped	No	No	
21C	0	Bolted & Taped	No	No	
22C	0	Bolted & Taped	No	No	
23C	0	Bolted & Taped	No	No	
24C	0	Bolted & Taped	No	No	
25C	0	Bolted & Taped	No	No	
26C	0	Bolted & Taped	No	No	
27C	0	Bolted & Taped	No	No	
28C	0	Bolted & Taped	No	No	
29C	0	Bolted & Taped	No	No	
30C	0	Bolted & Taped	No	Yes	2 min. to propagation
31C	0	Bolted & Taped	No	Yes	2 min. to propagation
32C	0	Bolted & Taped	No	No	
33C	0	Bolted & Taped	No	No	
34C	0	Bolted & Taped	Yes	Yes	2 & 5 min. to propagation
35C	0	Bolted & Taped	No	Yes	3 min to propagation
36C	0	Bolted & Taped	Yes	No	Simultaneous propagation
37C	0	Bolted & Taped	No	No	
38C	0	Bolted & Taped	No	No	
39C	0	Bolted & Taped	No	No	
40C	0	Bolted & Taped	No	No	
41C	0	Bolted & Taped	Yes	No	Simultaneous propagation

* 50 igniters in each box.

TABLE VIII . HAZARD CLASSIFICATION TESTS
PROJECT 2610 - CBI IGNITERS*

SwRI Test No.	Box Separation (Edge-to-Edge) (meters)	Box Lid and Handholds	Propagation Acc #1	Propagation Acc #2	Remarks
10E	0	Taped	Yes	Yes	2 & 4 min. to propagation
11E	0.6	Bolted & Taped	No	No	
12E	0.6	Bolted & Taped	No	No	
13E	0.6	Bolted & Taped	No	No	
17E	0.3	Bolted & Taped	No	No	
66C	0.3	Bolted & Taped	No	No	
67C	0.3	Bolted & Taped	No	No	
68C	0.3	Bolted & Taped	No	No	
69C	0.3	Bolted & Taped	No	No	
70C	0.3	Bolted & Taped	No	No	
71C	0.3	Bolted & Taped	No	No	
72C	0.3	Bolted & Taped	No	No	
73C	0.3	Bolted & Taped	No	No	
74C	0.3	Bolted & Taped	No	No	
75C	0.3	Bolted & Taped	No	No	
76C	0.3	Bolted & Taped	No	No	
77C	0.3	Bolted & Taped	No	No	
78C	0.3	Bolted & Taped	Yes	No	1 min. to propagation
79C	0.3	Bolted & Taped	Yes	No	3 min. to propagation
80C	0.3	Bolted & Taped	No	Yes	30 sec. to propagation
81C	0.3	Bolted & Taped	No	No	
82C	0.3	Bolted & Taped	No	Yes	2 min. to propagation
83C	0.3	Bolted & Taped	No	No	
84C	0.3	Bolted & Taped	No	No	
85C	0.3	Bolted & Taped	No	No	
86C	0.3	Bolted & Taped	No	No	
87C	0.3	Bolted & Taped	Yes	No	3 min. to propagation
88C	0.3	Bolted & Taped	No	No	
89C	0.3	Bolted & Taped	No	Yes	2 min. to propagation

* 50 igniters in each box

confirmatory tests did fire propagation occur, and in each instance it was a relatively long time to propagation. This time delay is indicative of the fact that propagation occurred via a burning bag dropped on top of the acceptor which eventually burned through the lid and caused propagation.

It was established from these tests that a safe separation of 0.3 m would be adequate to prevent immediate propagation; however, it would be advisable to install a water deluge system on the conveyor line to extinguish random fires as they might occur. More will be said on this subject in the following paragraphs.

The next series of hazard classification tests was conducted with the center core igniters in the plastic transport box, and because of their larger size, only 25 center core igniters were placed in each box. These can be seen prior to test in Figure 22 and a typical test set-up is shown in Figure 23. When the handholds of the boxes were taped closed and the lids bolted down, no propagation occurs as shown in Figure 24. Here the donor lid has been blown open yet no fire propagation occurred at 0 meters standoff. The results of all of the tests are given in Table IX for five exploratory shots followed by a total of 25 confirmatory tests, thus again a total of 50 evaluations was made. For the center core igniters only in three out of 50 evaluations was there propagation from the donor to the acceptor tote bin. In each case the propagation of the fire took a relatively long time and was caused by the random occurrence of having an igniter ejected from the donor box and alighting on top of an acceptor box. The center core igniters burned much less vigorously than did the base pad igniters, this no doubt being due to the fact that the base pad igniters contained 142 gm of black powder, whereas the center core igniters contained only 84 grams.

The hazard classification tests of the three types of igniters which were evaluated clearly indicated that in no case did a detonation occur; therefore, the igniter assembly lines at the Indiana, Kansas, Iowa and Lone Star AAP's should be classified as a 1.3 fire hazard as opposed to a 1.1 mass detonation hazard. Propagation of a fire from the donor to the acceptor tote bin occurs only on a random basis, and usually after a long delay. This fire propagation is usually caused by an igniter bag being ejected from the donor box and randomly lights on an acceptor box, subsequently burning through the lid and causing a fire in the acceptor. This problem could easily be eliminated through the use of a water deluge system, a solution which has been tested and evaluated and will be reported in the succeeding paragraphs.

Two recommendations, both with a simple remedy, are made as a result of the test observations. In order to prevent the initial puff of gas which is generated upon ignition of the donor box from getting through the handholds of the box or from lifting the lid off of adjacent boxes, the handholds should be taped shut and the lids of boxes should be bolted closed. The terms "taped" and "bolted" are descriptive of the remedies used for this test series. In the actual in-plant situation, it is recommended that the Nestier plastic boxes with the handholds already molded shut be used and that the boxes be equipped with latch fittings to hold lids in place. These are simple and inexpensive remedies, yet are of utmost importance for the prevention of fire propagation down an in-plant conveyor line.

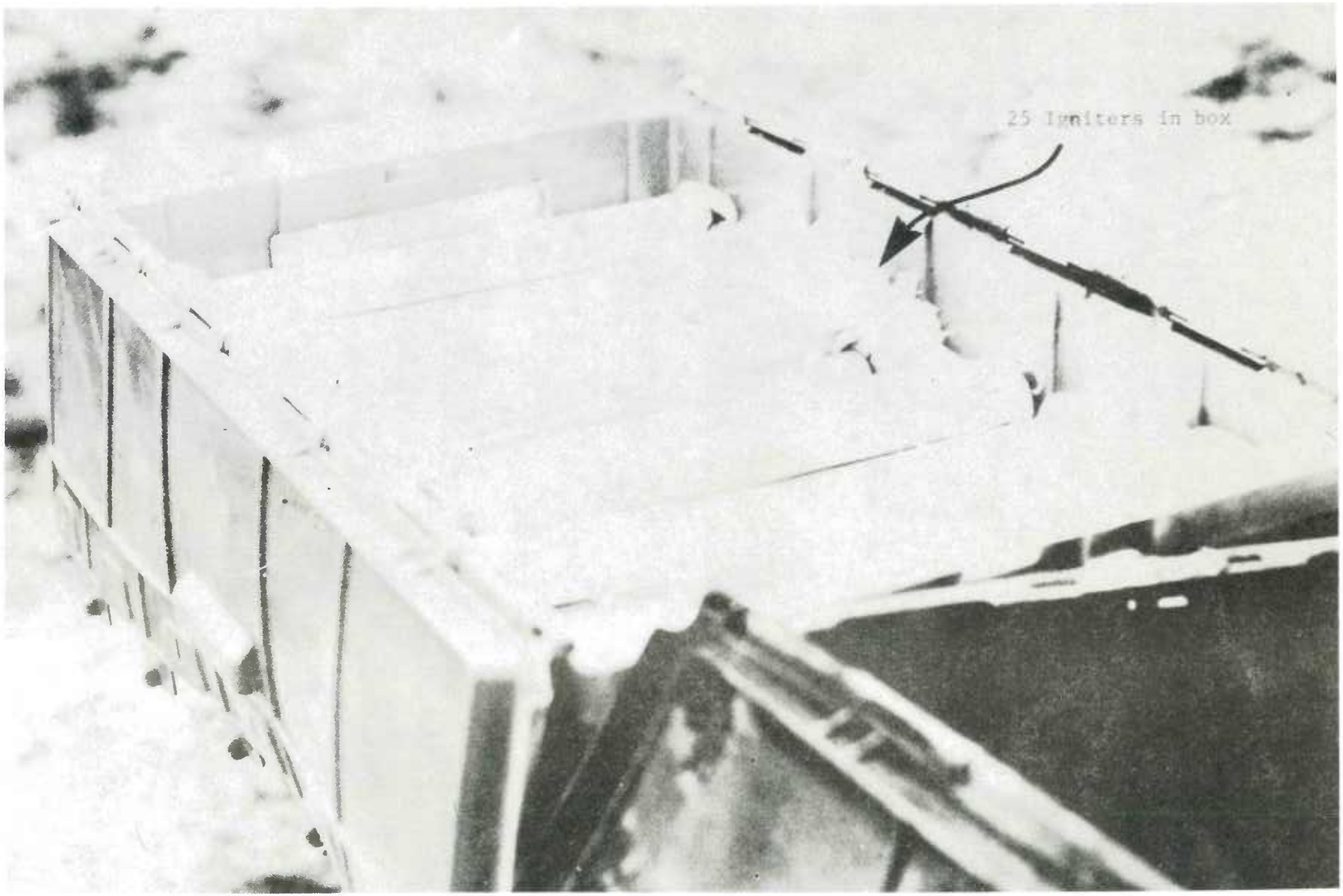


FIGURE 22. PROJECT 2694 - CENTER CORE IGNITERS IN TRANSPORT BOX

FIGURE 23. PROJECT 2694 - SAFE SEPARATION TESTS OF BOXED CENTER CORE IGNITERS

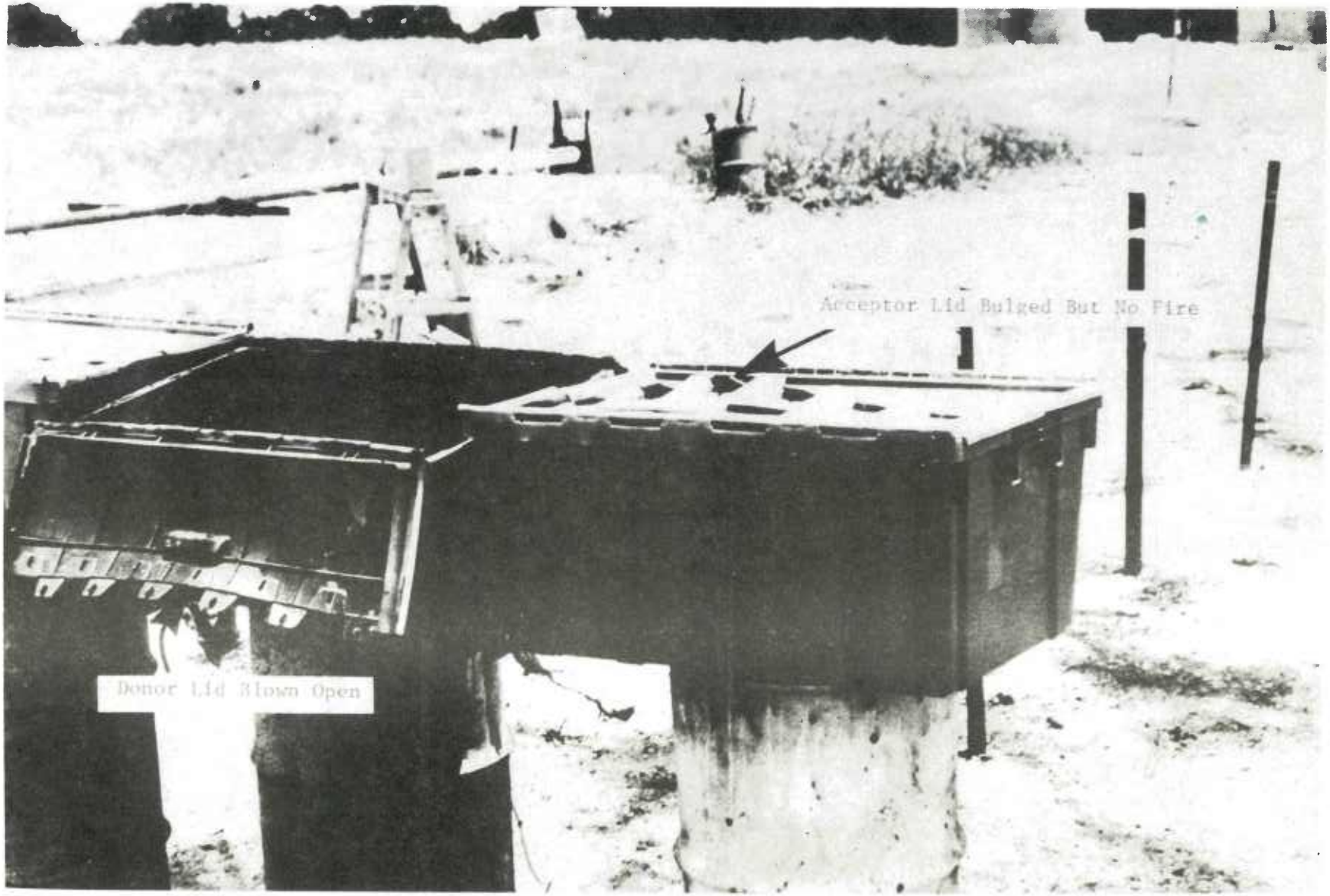


FIGURE 24. PROJECT 2694 - NO FIRE PROPAGATION AT 0 METER STANDOFF

TABLE IX. HAZARD CLASSIFICATION TESTS
PROJECT 2694 - CENTER CORE IGNITERS*

SwRI Test No.	Box Separation (Edge-to-Edge) (meters)	Box Lid and Handholds	Propagation Acc #1	Propagation Acc #2	Remarks
5E	0	Taped	Yes	Yes	2 min. to propagation
6E	1.2	Taped	No	No	
7E	1.2	Bolted & Taped	No	Yes	1 min. to propagation
8E	0	Bolted & Taped	No	No	
16E	0.3	Bolted & Taped	No	No	
42C	0	Bolted & Taped	No	No	
43C	0	Bolted & Taped	No	No	
44C	0	Bolted & Taped	No	No	
45C	0	Bolted & Taped	No	No	
46C	0	Bolted & Taped	No	No	
47C	0	Bolted & Taped	No	No	
48C	0	Bolted & Taped	No	No	
49C	0	Bolted & Taped	No	Yes	Top lid was partially open
50C	0	Bolted & Taped	No	No	
51C	0	Bolted & Taped	No	Yes	2-1/2 min. to propagation
52C	0	Bolted & Taped	No	No	
53C	0	Bolted & Taped	No	No	
54C	0	Bolted & Taped	No	No	
55C	0	Bolted & Taped	No	No	
56C	0	Bolted & Taped	No	No	
57C	0	Bolted & Taped	No	No	
58C	0	Bolted & Taped	No	No	
59C	0	Bolted & Taped	No	No	
60C	0	Bolted & Taped	No	No	
61C	0	Bolted & Taped	No	No	
62C	0	Bolted & Taped	No	No	
63C	0	Bolted & Taped	No	No	
64C	0	Bolted & Taped	No	No	
65C	0	Bolted & Taped	Yes	No	10 sec. to propagation

* 25 igniters in each box

Water Deluge for Igniter Boxes on a Conveyor System

As a remedy for the long term potential fire hazard resulting from a fire on the boxed igniter conveyor line, a water deluge system is recommended. The design of a typical system has been tested and is shown in Figures 25 and 26. Here a dual conveyor line transporting boxed igniters is shown being protected by a single water line which covers both the upper and lower conveyors. A UV detector is used to sense the occurrence of a fire and this detector triggers a high speed Primac water release valve. Each of the fire tests was monitored by high speed camera and flash bulbs were used to monitor the events on high speed film. Four events were monitored: 1) ignition of the fire, 2) detection by the UV detector, 3) activation of the Primac water valve, and 4) the release of water from the deluge nozzles. In a typical test six boxes were used, three on the upper conveyor and three on the lower conveyor; an ignition was always caused in the center bottom box. The smoke and flame five seconds after ignition resulting from the fire in this center bottom box is shown in Figure 27 and Figures 28 and 29 are photographs of the results of the test. The bagged igniters in the donor box have been, for the most part, ejected and were strewn around the test pad and on top of the acceptor boxes. Figure 29 is a close-up view of an acceptor box on which a flaming igniter bag obviously landed. With the protection of the water deluge system, however, this fire was extinguished before the lid was burned through and before propagation occurred.

The water deluge protection system was evaluated for use in the two most severe situations, i.e., for the black powder base igniters and for the CBI igniters. The water deluge system was not tested against the center core igniters since these are much slower burning igniters and consequently pose a less severe problem. The results of the test series for the black powder base igniters are given in Table X and for the CBI igniters in Table XI. All of the tests were conducted with a static water pressure of 207 kPa, a pressure corresponding to the available line pressures at the ammunition plants. In all cases, the plastic boxes were taped and bolted and in all cases a 0 meter separation was used. The tests clearly indicate that the water deluge system is most effective in preventing fire propagation. In only one instance out of 31 test firings did propagation occur. In this case, Shot 10(e) listed in Table XI, the water system was shutdown within 30 seconds after the occurrence of the event and obviously the fire was not completely out because propagation did occur to Acceptor No. 1 after a waiting period of five minutes. This single event was judged to be due to an atypical situation since, should an event occur in an ammunition plant, the water system would not be shutdown within 30 seconds.

The results of the water deluge tests clearly indicated that a water deluge system should be used along the conveyor lines which transport bagged igniters. The deluge system is most effective in extinguishing extraneous fires and will permit a 0 meter safe separation distance between the transport boxes. Since the test series has shown that propagation from one transport box to the next is not immediate and time to propagation is in seconds versus milliseconds, the water system can be relatively slow in responding. In addition, effective coverage can be maintained, with little water application, through a single water line mounted in an easily accessible position adjacent to the conveyor line.

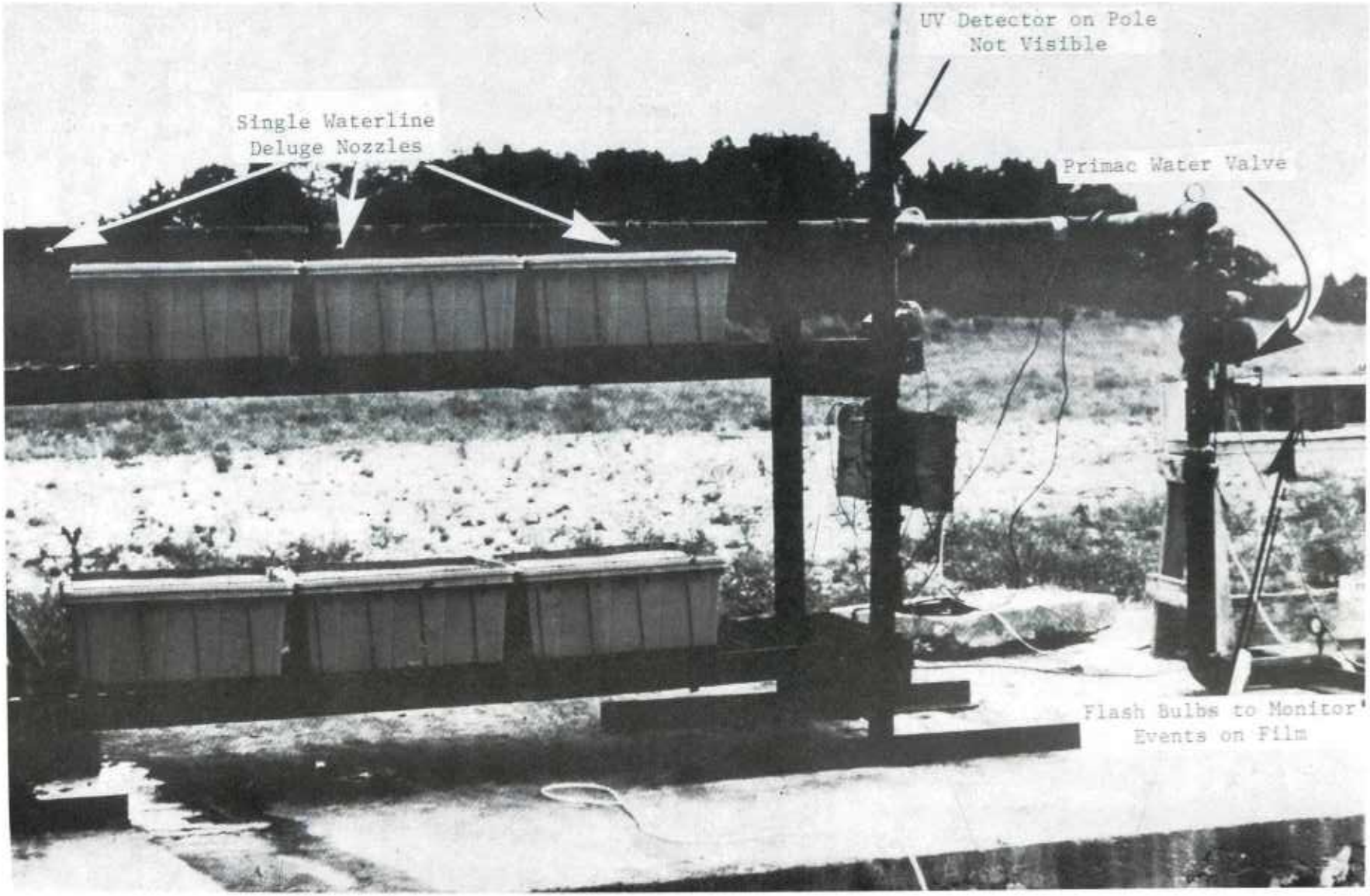


FIGURE 25. FIRE PROTECTION SYSTEM FOR DUAL CONVEYOR LINE TRANSPORTING BOXED IGNITERS

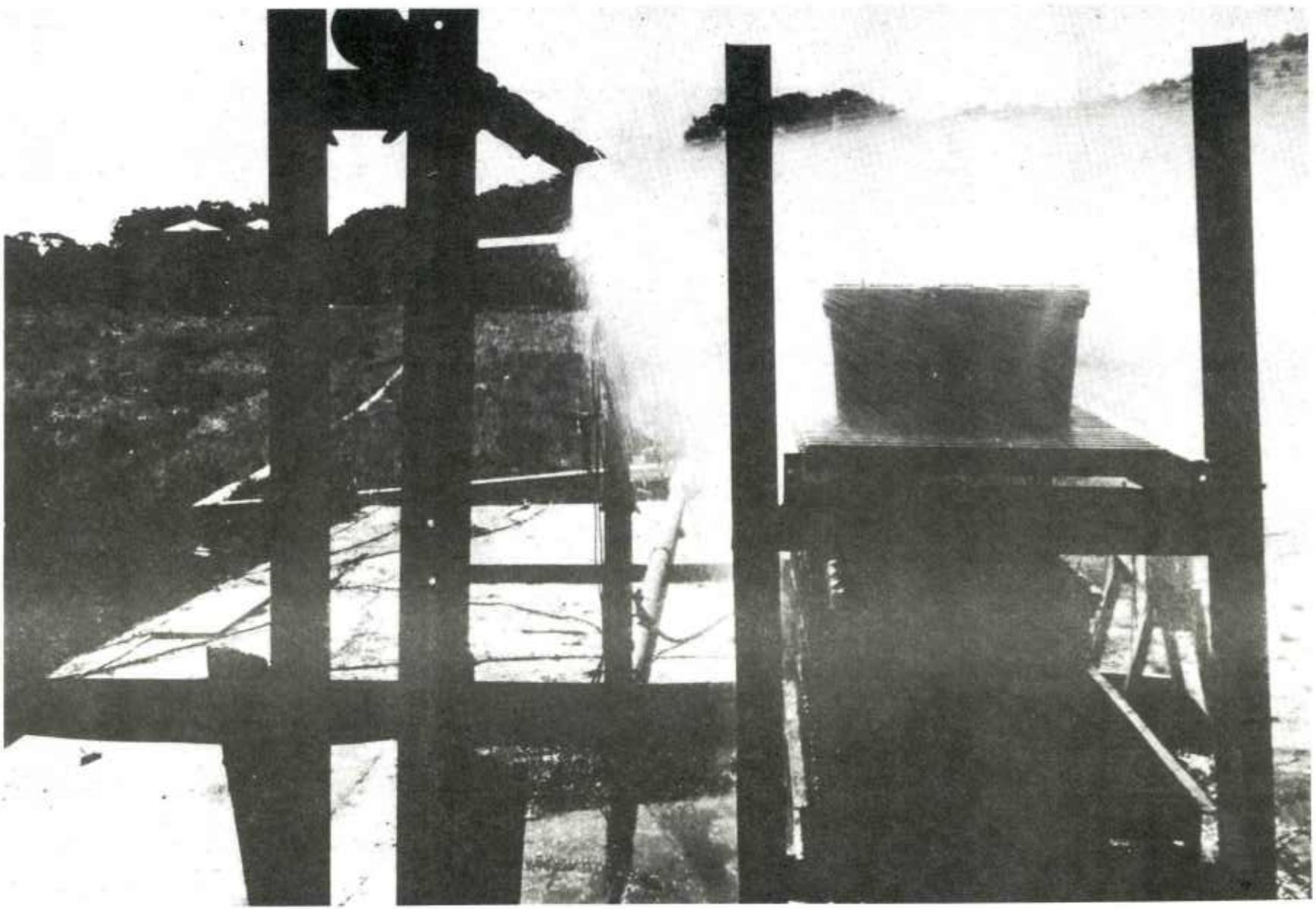


FIGURE 26. PATTERN OF SINGLE LINE SYSTEM PROTECTING UPPER AND LOWER CONVEYORS

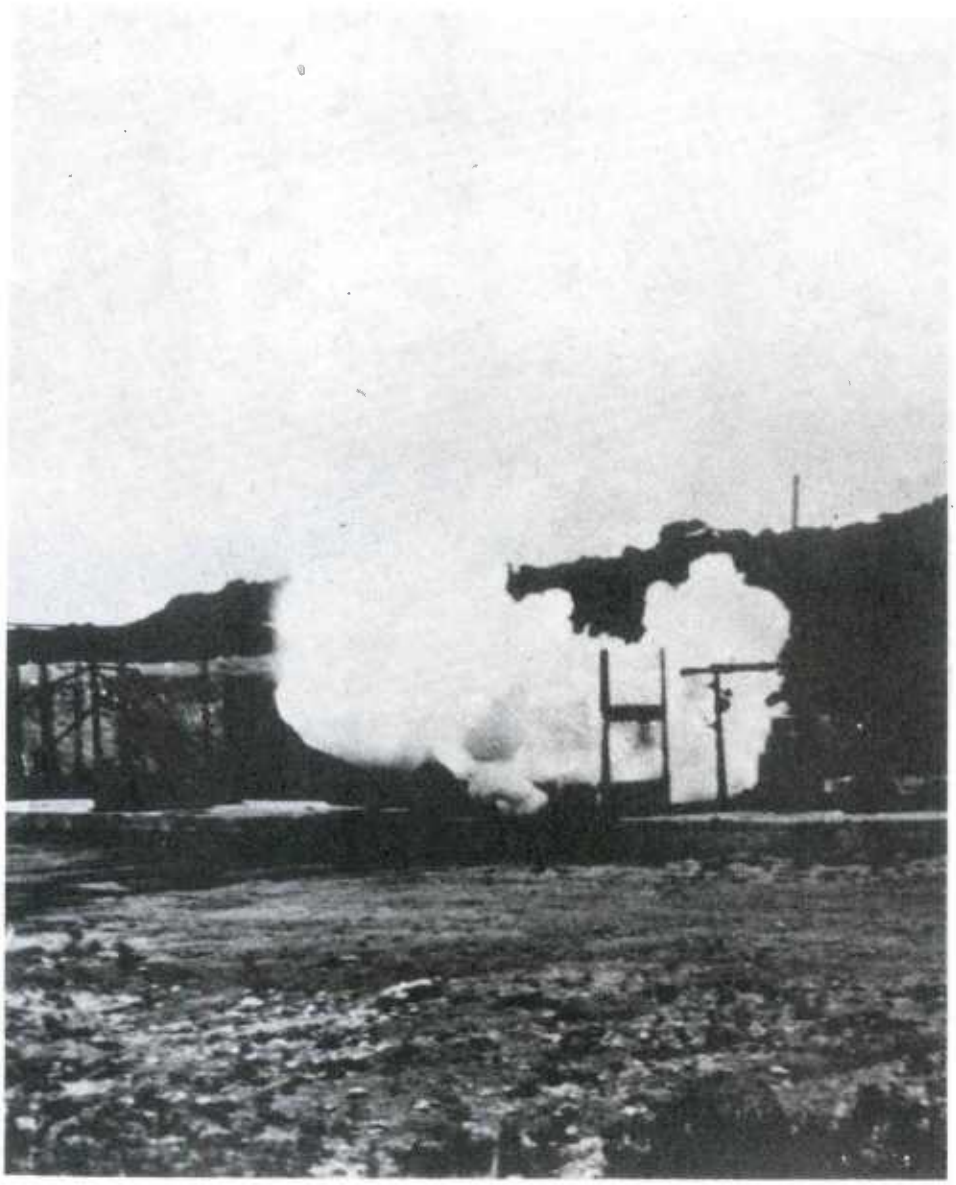


FIGURE 27. ERUPTION OF FIRE FROM CENTER - BOTTOM BOX
5 SEC. AFTER IGNITION

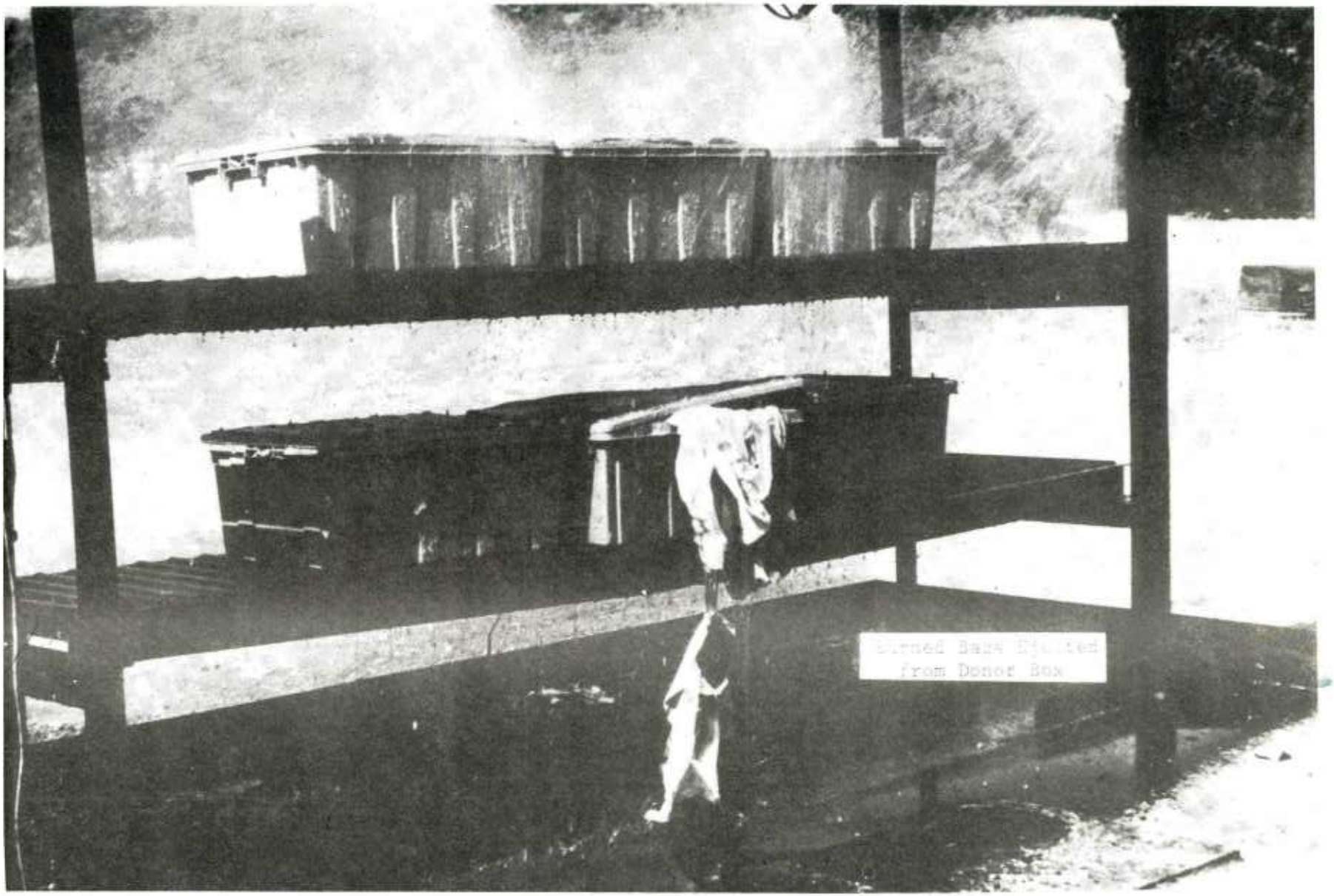


FIGURE 28. RESULTS OF DELUGE TEST - ALL ACCEPTOR BOXES PROTECTED BY WATER SYSTEM

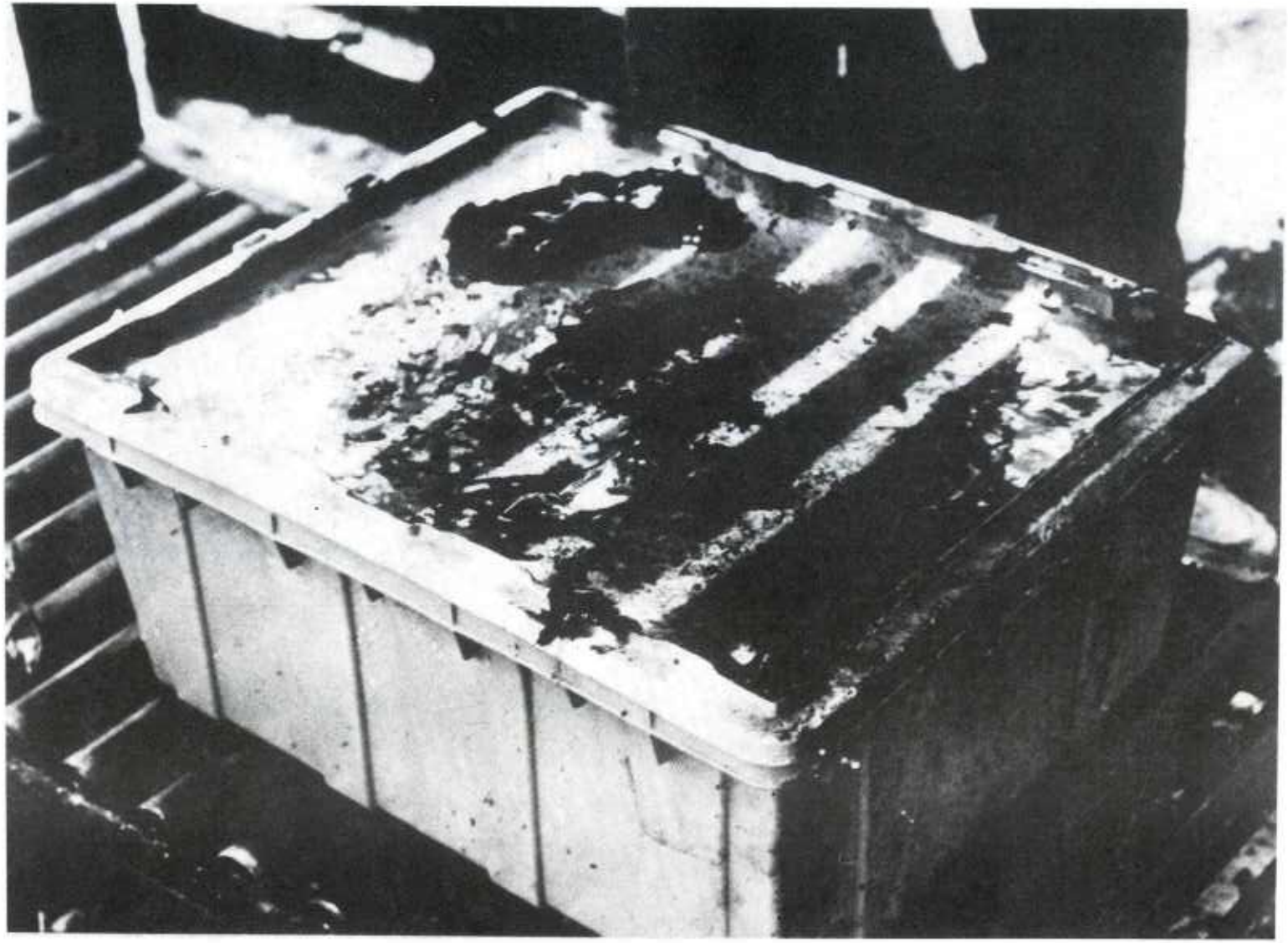


FIGURE 29. CLOSE-UP VIEW OF ACCEPTOR BOX SHOWS FIRE WOULD HAVE BURNED THROUGH LID WITHOUT DELUGE SYSTEM

TABLE X

SUMMARY OF WATER DELUGE TESTS

. PROJECT 2610 - BLACK POWDER IGNITERS

SwRI Test No.	Box Sepsration (Edge-to-Edge)	Box Lids/Handholds	Propagation				
			Acc 1	Acc 2	Acc 3	Acc 4	Acc 5
1E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
2E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
3E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
4E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
9E	None(Butted)	Bolted & Taped	No	No	No	No	No
11C	None(Butted)	Bolted & Taped	No	No	No	No	No
12C	None(Butted)	Bolted & Taped	No	No	No	No	No
13C	None(Butted)	Bolted & Taped	No	No	No	No	No
14C	None(Butted)	Bolted & Taped	No	No	No	No	No
15C	None(Butted)	Bolted & Taped	No	No	No	No	No
16C	None(Butted)	Bolted & Tsped	No	No	No	No	No
17C	None(Butted)	Bolted & Taped	No	No	No	No	No
18C	None(Butted)	Bolted & Taped	No	No	No	No	No
19C	None(Butted)	Bolted & Taped	No	No	No	No	No
20C	None(Butted)	Bolted & Taped	No	No	No	No	No
21C	None(Butted)	Bolted & Taped	No	No	No	No	No

All the above tests were conducted with a static water pressure of 207 kPa.

Exploratory tests 1, 2, 3, 4, and 9 were conducted with 1C-5-100-16 nozzles and a vertical separation between tiers of contsiners at 0.6 m.

All confirmatory tests (11 thru 21) were conducted with a vertical separation between tiers of containers at 0.3 m. Nozzles used were 1C-5-50-12.

TABLE XI

SUMMARY OF WATER DELUGE TESTS
PROJECT 2610 - CBI IGNITERS

SwRI Test No.	Box Separation (Edge-to-Edge)	Box Lids/Handholds	Propagation				
			Acc 1	Acc 2	Acc 3	Acc 4	Acc 5
5E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
6E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
7E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
8E	None(Butted)	Bolted & Taped	No	No	Not Used	Not Used	Not Used
10E	None(Butted)	Bolted & Taped	Yes	No	No	No	No
22C	"	Bolted & Taped	No	No	No	No	No
23C	"	Bolted & Taped	No	No	No	No	No
24C	"	Bolted & Taped	No	No	No	No	No
25C	"	Bolted & Taped	No	No	No	No	No
26C	"	Bolted & Taped	No	No	No	No	No
27C	"	Bolted & Taped	No	No	No	No	No
28C	"	Bolted & Taped	No	No	No	No	No
29C	"	Bolted & Taped	No	No	No	No	No
30C	"	Bolted & Taped	No	No	No	No	No
31C	"	Bolted & Taped	No	No	No	No	No

Exploratory tests 5 thru 8 and test 10 were conducted with IC-5-100-16 nozzles. All confirmatory tests (22 thru 31) were conducted with IC-5-50-12 nozzles.

Exploratory test No. 10 and all confirmatory tests were conducted with a vertical separation between tiers of containers at 0.3 m. Exploratory tests 5 thru 8 were at 0.6 m vertical separation.

All tests were conducted with a static water pressure of 207 kPa.

CONCLUSIONS

A summary of the safe separation and critical height test results as discussed in this report is given in Table XII. A brief recap of those results is as follows:

1. Safe separation tests of cardboard drums containing 2.3 kg of M-10 propellant indicated that these drums could be touching one another without risk of fire propagation. In no case did the M-10 fire transcend into a high order detonation.

2. When the M-10 propellant is transfered to a loading hopper with stack, a critical height not to exceed 31.8 cm must be maintained in order to prevent the transition to high order detonation. A water deluge system can potentially be used as a fire deterrent, however, tests will have to be conducted to determine the deluge parameters.

3. After the M-10 propellant has been loaded into 81 mm mortar increments, these increments must be separated by at least 25.4 cm without a fire barrier or this distance can be reduced to 7.6 cm if a simple barrier is used. Fire containment without a barrier can be readily achieved with a deluge system. Tests to establish the deluge parameters will have to be conducted.

4. When the 81 mm mortar increments are released from their fixtures and dumped into a storage bin, a height of 45.7 cm (500 increments) will constitute a safe quantity eliminating any possibility of a fire transcending into a high order detonation.

5. M-1 propellant is normally transported in a cardboard drum containing 68 kg of the propellant. When these drums are transported along a roller conveyor system, a minimum safe separation of 4.6 m should be maintained. Although it was demonstrated that a detonation would not occcur, the occurrence of random fires is always a possibility and should be countered by the use of a water deluge system within the tunnel confinement.

6. The series of tests evaluating the black powder and CBI base igniters and the center core igniters clearly indicated that in no case would a detonation occur in one of the transport boxes. In all of the tests, however, it was shown that the igniters would be tossed out of the plastic transport box and could land in a random fashion up and down the conveyor line. Again, it was demonstrated that a water deluge system should be used to extinguish these extraneous fires and would be most effective in reducing the safe separation distance to 0 meters without risk of fire propagation.

TABLE XII

Summary of Safe Separation and Critical Height Test Results

	Item	Safe Separation	Critical Hgt.
I	2.3 kg of M-10 in cardboard drums	Touching	-
II	M-10 Loading Hoppers	Not established +	-
III	Critical Hgt. of M-10 in Hoppers with 3 m Stack	-	31.8 cm
IV	81 mm Increments on Fixtures	7.6 cm w/barrier 25.4 cm w/o barrier	-
V	81 mm Increments in Storage Bin	-	45.7 cm
VI	M-1 Propellant in 68 kg drums	4.6 *	-
VII	Black Powder Base Igniters in Plastic Boxes	Touching *	-
VIII	CBI Base Igniters in Plastic Box	0.3 *	-
IX	Center Core Igniters in Plastic Boxes	Touching *	-

* Water deluge recommended to extinguish extraneous fires (See Table X and XI).

+ No test required if hopper with stack is used and bed depth of propellant less than 31.8 cm. Water deluge tests will have to be conducted if hopper used without stack.

RECOMMENDATIONS

1. The test series established a critical height for M-10 propellant in loading hoppers not to exceed 31.8 cm and propellant contents of the hopper should not be above this level as a detonation could occur.

2. To prevent fire propagation along the 81 mm mortar increment loading line, a simple barrier should be used between the fixtures to both reduce the safe separation distance and to eliminate possibility of fire. Deluge system design required to prevent propagation of fire from one fixture to another without barriers.

3. Five hundred 81 mm mortar increments in a storage bin will not transcend into a high order detonation and hence, can be classified as a 1.3 fire hazard.

4. Transport drums of M-1 propellant will not explode should a fire occur within the drum. A safe separation distance of 4.6 m was established; however, extraneous fires should be eliminated or extinguished through the use of a water deluge system along the conveyor line.

5. Plastic boxes transporting the igniter bags to the final loading operation will not detonate. However, burning bags will be ejected from the donor box in a random fashion up and down the transport line. Hence, a water deluge system should be used to combat these extraneous fires. These boxes should be molded with closed handholds and a latch to secure the lids.

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